Sampling Ontario Lake Trout Stocks
Issues and Standards

Lake Trout Synthesis
Sampling Issues and Methodology
Working Group
1991

Ontario
Ministry of
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Resources

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N. P. Lester
Research Section, Fisheries Branch
P.O. Box 5000, Maple, Ontario L6A 1S9

M. M. Petzold
Algoma Fisheries Assessment Unit
P.O. Box 130, Sault Ste Marie, Ontario P6A 5L5

W. I. Dunlop
Muskoka Lakes Fisheries Assessment Unit
P.O. Box 1188, Bracebridge, Ontario P1L 1V3

B. P. Monroe
Algonquin Fisheries Assessment Unit
P.O. Box 219, Whitney, Ontario K0J 2M0

S. D. Orsatti
Lake Erie Fisheries Assessment Unit
R.R. 2, Wheatley, Ontario N0P 2P0

T. Schaner
Lake Ontario Fisheries Assessment Unit
R.R. 4, Glenora, Ontario K0K 2T0

D. R. Wood
Kawartha Lakes Fisheries Assessment Unit
322 Kent Street West, Lindsay, Ontario K9V 2Z9

Ontario Ministry of Natural Resources

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ABSTRACT

Lester, N. P., M. M. Petzold, W. I. Dunlop, B. P. Monroe, S. D. Orsatti, T. Schaner, and D. R. Wood. 1990. Sampling Ontario lake trout stocks: issues and standards. Lake trout synthesis. Ont. Min. Nat. Resour. Toronto. 117 p.

A cost effective approach for evaluating the status of lake trout (*Salvelinus namaycush*) in Ontario lakes is developed. The approach calls for Fisheries Assessment Unit (FAU) and district lake assessment programs that are based on a common sampling framework, although they differ in terms of sampling intensity. Intensive trend-through-time studies of FAU lakes, monitoring variables such as harvest, effort, abundance, mortality, growth and condition, are necessary to develop models of lake trout systems and establish criteria for evaluating district lakes. Problems in estimating diagnostic variables are discussed and standard methods are proposed. These standards are designed to ensure greater comparability of results from studies among FAU lakes. This requires that the FAU network adopt a sampling framework that classifies surveys based on fishing method, season of the year and habitats sampled. Arguments are presented for choosing particular combinations of these factors as the best sources of data and for using a standardized index fishing method. Lower cost point-in-time assessment methods are developed for district lakes using historical FAU data to identify functional relationships between easily obtained statistics and variables of concern. Effort and catch indexing programs are presented as a means of evaluating lakes on a district wide basis. Interpretation of district lake statistics relies on the FAU program to provide reference values against which results can be compared. Valid comparisons require that both FAU and district lake programs are based on the same sampling framework.

INTRODUCTION

District fisheries managers in Ontario face difficult tasks in evaluating the status of lake trout (*Salvelinus namaycush*), or any species, in lakes within their areas of jurisdiction. Traditional methods of assessment call for intensive long-term studies within a lake to monitor properties such as harvest, effort, abundance, mortality and growth. Such methods cannot be afforded given the large number of lakes within most districts. Nor can they be justified when the cost of sampling an individual lake can easily exceed the value of its fishery. Stock assessment, in these situations, requires alternative methods that reduce the cost of sampling individual lakes, yet provide the information needed to evaluate the status of fish populations and, hence, decide whether management action is needed.

The Ontario Ministry of Natural Resources (OMNR) initiated a new assessment strategy in the 1970s, when it adopted the comparative lakes approach to fisheries management. This approach proposes that effective management is possible without intensive monitoring of all lakes. It is based on a principle, emerging from syntheses of salmonid (Loftus and Regier 1972) and percid (Colby and Wigmore 1977) communities, that similar communities react to the same stresses in similar ways. Thus, knowledge gained from intensive study of a representative set of lakes can be applied to other lakes with similar properties. Committment to this principle resulted in the selection of a set of type lakes and the creation of Fisheries Assessment Units (FAUs) to monitor these lakes on a trend-through-time basis (OMNR 1978). This program is expected to provide an understanding of how fish populations respond to stress, and to devise indices useful for evaluating conditions in district lakes (OMNR 1984a; OMNR 1984b; OMNR 1988).

A comparative approach to fisheries management places heavy demands on the FAU network to provide managers with cost effective assessment methods. Examples of the types of tools needed exist in the report of SPOF Working Group Number Fifteen (OMNR 1983), Hoyle and Stewart (1987) and more recent reports by various lake trout synthesis working groups (Carl et al. 1990, MacLean et al. 1990, Payne et al. 1990, Evans et al. 1991). These reports describe how various measures (including effort, harvest,

abundance, age structure, total mortality, mean age of the catch, variation in year-class strength, and growth) serve as indicators of overexploitation. For each measure, attempts were made, using data from intensively studied lakes, to define some reference level against which results for a particular lake could be compared to evaluate stress. For some indicators, it was possible to identify a reference value that could be viewed as a threshold for concern. For others, this reference was simply a benchmark, the average of what was observed in study lakes.

This paper describes two types of lake trout assessment programs: one for FAU lakes and the other for district lakes. The programs differ in terms of objectives and sampling intensity, but they are based on a common sampling framework that ensures the comparability of FAU and district lake information. This framework is described in the subsequent section. It identifies sources of data and important factors (season, habitat, fishing method) that must be controlled when evaluating the status of lake trout populations.

Diagnostic variables are discussed in two subsequent sections, entitled "harvest, effort and abundance" and "mortality, growth and condition". We suggest reference values for evaluating district lakes, discuss measurement problems and develop some low cost assessment methods. The proposed reference values are based on a small sample of lakes and should be updated when more time series data are available. The FAU program supplies data for this purpose; the district lake program obtains only the information needed to examine how variables deviate from reference values.

Although general guidelines for monitoring of FAU lakes are given by the FAU core data program (OMNR 1990), standardized methods of assessment have not been described. We propose measurement standards and describe the data collection and processing methods that are needed on FAU lakes. The section entitled "Sampling FAU Lakes" describes a typical year of sampling and demonstrates the

application of these standards. Also, we supply sample size guidelines, indicating how much sampling is needed to estimate these variables at standard levels of precision.

The objective of the district lake sampling program is to describe the status of lake trout within a geographical region (e.g. an entire district or portion of a district). This requires sampling of many lakes and necessitates the avoidance of costly sampling procedures. The section entitled "Sampling District Lakes" describes the use of low cost assessment methods developed in this paper. It identifies the information required from district lakes, specifies how much sampling should be done and describes how results could be used to classify lakes and describe the status of lake trout in a geographical region.

SAMPLING FRAMEWORK

FAU and district lake sampling programs will be discussed within the sampling framework shown in Fig. 1. Sport and index fishing are the two primary sources of data. Commercial fishing offers an additional source, but the use of these data will not be discussed because commercial fisheries for lake trout do not exist on most Ontario lakes.

Sampling of the sport fishery must be done on a seasonal basis. This is necessary to ensure the comparability of information obtained from FAU and district lakes. Seasons are identified in Fig. 1 as quarters of the year: winter (January-March), spring (April-June), summer (July-September) and fall (October-December). The winter season, which is supposed to represent ice fishing, ends on March 31 and should be extended for more northern lakes where ice fishing often occurs during April.

Index fishing in Ontario has employed a variety of fishing gear to sample various habitats in various seasons. An indexing program should be designed so that survey results are comparable among lakes, as well as through time within a lake. Standards are needed that identify the type of gear, when, where and how it is used. Randomization of sampling sites within defined habitats is necessary; otherwise,

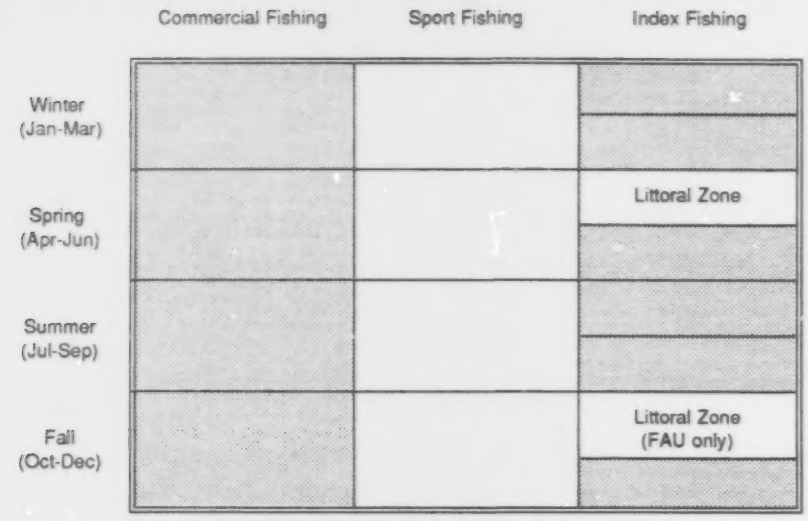


Fig. 1. Sampling framework for the assessment of lake trout on FAU and district lakes. Cells identify sources of data available for studying fish populations. Open cells represent strata that are sampled.

comparisons among lakes are nothing more than comparisons among unique sites which happen to occur in different lakes.

The proposed method for lake trout assessment is described in Appendix A. It uses 30-minute sets of small-mesh gill nets to sample the littoral zone during the spring season. The technique, which has been used at several FAUs (i.e. Algoma, Algonquin and Muskoka), is efficient in capturing lake trout of various sizes. A similar method has been used for many years in the Experimental Lakes Area (Mills et al. 1987). Because lake trout are entangled, not wedged, by the gear, the method does not kill fish and thus minimizes the impact of sampling. This is important on small lakes where killing fish for assessment purposes could be a major stress on the fish population.

The sampling framework in Fig. 1 also indicates that FAUs will use index fishing methods during the fall. This refers to fall tagging, which is done by capturing lake trout on spawning shoals. Strictly speaking, this

is not an 'index' survey. Fall netting at spawning shoals is undertaken so that a large sample of fish can be tagged in a cost effective manner. Recaptures of tagged fish (by anglers and spring index fishing) provide important data for verifying assumptions made in various assessment procedures. For example, estimates of absolute abundance obtained from mark-recapture data allow catch-per-unit-effort (CUE) to be calibrated as an index of abundance. Such data can also be used to estimate catchability and size selectivity of angling and index fishing gear. These issues are discussed in this paper, but tagging is not included in the standard FAU program because, for cost reasons, it cannot be done on all FAU lakes. As recommended by the FAU core data program (OMNR 1990), tagging studies on a sample of FAU lakes supplies sufficient information.

HARVEST, EFFORT AND ABUNDANCE

SURPLUS PRODUCTION THEORY

Surplus production models (Schaefer 1954, 1957; Ricker 1975; Schnute 1977; Gulland 1983; Pauly 1984; Lleonart and Salat 1989) have been widely used in fisheries management to set target levels for effort and harvest. Their development requires long time series of annual harvest (in weight) and effort data which span a wide range of effort levels. Theory predicts that for a given level of effort, harvest stabilizes at a particular level and that a dome-shaped relationship exists between sustainable (i.e. long-term stable) harvest and effort (Fig. 2a). The highest point on this dome identifies maximum sustainable harvest and supplies a reference point for evaluating the health of a population. The corresponding value of fishing effort can be interpreted as optimal effort and applied as a criterion for classifying lakes as under- or overexploited.

This production model implies a relationship between effort and abundance which is also useful for evaluating the status of a fish population. To illustrate this point, we use harvest-weight-per-unit-effort (HUEW) as an index of abundance. Its relationship with effort is implied directly by the model because its value equals the slope of a line drawn from the origin to a point on the harvest-effort curve (Fig 2a). As

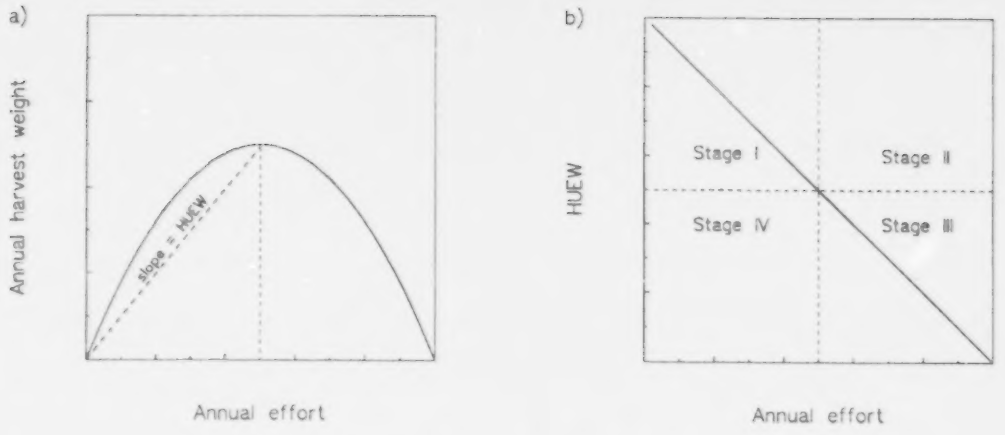


FIG. 2. Equilibrium relationships predicted by surplus production theory. In a), sustainable harvest is plotted against fishing effort. The slope of a diagonal line from the origin to a point on the curve measures harvest-weight-per-unit-effort (HUEW), an index of abundance. In b), the relationship between HUEW and effort is shown. Values of effort and HUEW associated with the maximum sustainable harvest identify four stages in fishery development.

shown in Fig. 2b, HUEW decreases as effort levels increase. The value of HUEW at optimal effort indicates what level of abundance exists under maximum sustainable conditions. Thus, if the assessed value of HUEW exceeds this threshold one concludes that the lake has not yet suffered from overexploitation, and vice versa if HUEW is less than the critical value. A critical abundance value could also be expressed in terms of other measures of abundance such as angling catch-per-unit-effort in number of fish (CUE) or mean catch rates from a standardized index netting program. These alternatives are discussed later.

Production models supply effort and abundance criteria that allow a population to be classified into various stages of fishery development. These stages, shown in Fig. 2b as four quadrats demarcated by optimal effort and abundance line, are described as follows.

- Stage I (underdeveloped): low effort and high abundance. These conditions are expected during the early stages of fishery development and also in rehabilitated fisheries. They indicate that an increase in effort is expected to result in an higher sustainable harvest.
- Stage II (overdeveloped-early): high effort and high abundance. These conditions are expected only during the early stages of overexploitation because stable combinations of effort and abundance do not exist in this quadrat. It represents a transient stage in an overexploited fishery and indicates a decline in abundance is expected if effort levels remain high.
- Stage III (overdeveloped-late): high effort and low abundance. It signifies that the population is being exploited beyond maximum sustainable harvest and the expected decline in abundance has occurred. A reduction in effort is expected to increase the sustainable harvest.
- Stage IV (recovery): low effort and low abundance. These conditions signify that a population has been overexploited in the past. It can result because management action has imposed effort restrictions on a stage III fishery. It is also expected in the natural course of fishery development because anglers are likely to shift their effort to other lakes as they experience a decline in abundance. Stable combinations are not predicted in this quadrat. A gradual transition to stage I and the eventual re-establishment of the stable, high abundance levels is predicted if effort remains at low levels. The fishery is described as rehabilitated when this renewal of Stage I conditions has been achieved.

CRITERIA FOR EVALUATING DISTRICT LAKES

The characterization of a sustainable harvest-effort relationship and the identification of effort and abundance levels associated with maximum harvest is a difficult exercise. It requires long time series of data spanning a broad range of effort levels. Analyses are confounded by the fact that equilibrium conditions are rarely observed because effort is constantly changing and many years of constant effort may be needed before harvest settles at an equilibrium level. Furthermore, the relationship is expected to vary

among lakes because intrinsic properties (e.g. area, mean depth, community type) affect production characteristics.

We used Ontario lake trout production data summarized by Payne et al. (1990) to establish some reference values for evaluating district lakes. Payne et al. (1990) showed that maximum sustainable harvest of lake trout is predicted by thermal habitat volume (Christie and Regier 1988), a measure of lake trout habitat that is correlated with lake surface area. The relationship with lake area is shown in Fig. 3a, where the dotted line is the regression equation based on a sample of 19 lakes. Estimates of mean annual stable harvest are shown for the five smallest lakes (Christman, Bone, Flack, Chiblow/Denman, Opeongo) where exploitation was due to angling, not commercial fishing. We used the data from these 5 lakes (see Table 1 in Payne et al. 1990) to determine what effort and abundance levels are expected under maximum sustainable harvest conditions. Relationships with lake area existed for effort and HUEW, but not for CUE (Fig. 3b,c,d). These results suggest the following criteria for evaluating district lakes.

Optimal lake trout effort ($Effort^*$) increases roughly in proportion to the square root of lake area (Fig. 3b):

$$Effort^* = 155.7\ Area^{0.54} \qquad [1]$$

Reference values for lakes of different sizes can be calculated from this equation and compared with estimates of annual effort to classify lakes as high or low effort. For lake areas of 100, 1000 and 10000 ha, effort criteria of 1872, 6491 and 22505 ang-hr are implied. and the corresponding values for fishing intensity (effort per area) are 18.7, 6.5 and 2.3 ang-hr ha^{-1}. Their range is consistent with effort guidelines suggested elsewhere. Hoyle & Stewart (1987) reviewed historical data from 3 lakes, ranging in size from 214 to 1031 ha, and concluded that a fishing intensity of 10 ang-hr ha^{-1} yr^{-1} was too high for lake trout. Evans et al. (1990) suggested a range of 1.3 to 8.4 ang-hr ha^{-1} yr^{-1} as an acceptable level.

Optimal abundance, expressed in weight as HUEW, increases with lake area (Fig. 3c),

$$HUEW^* = 0.036\ Area^{0.22} \qquad [2]$$

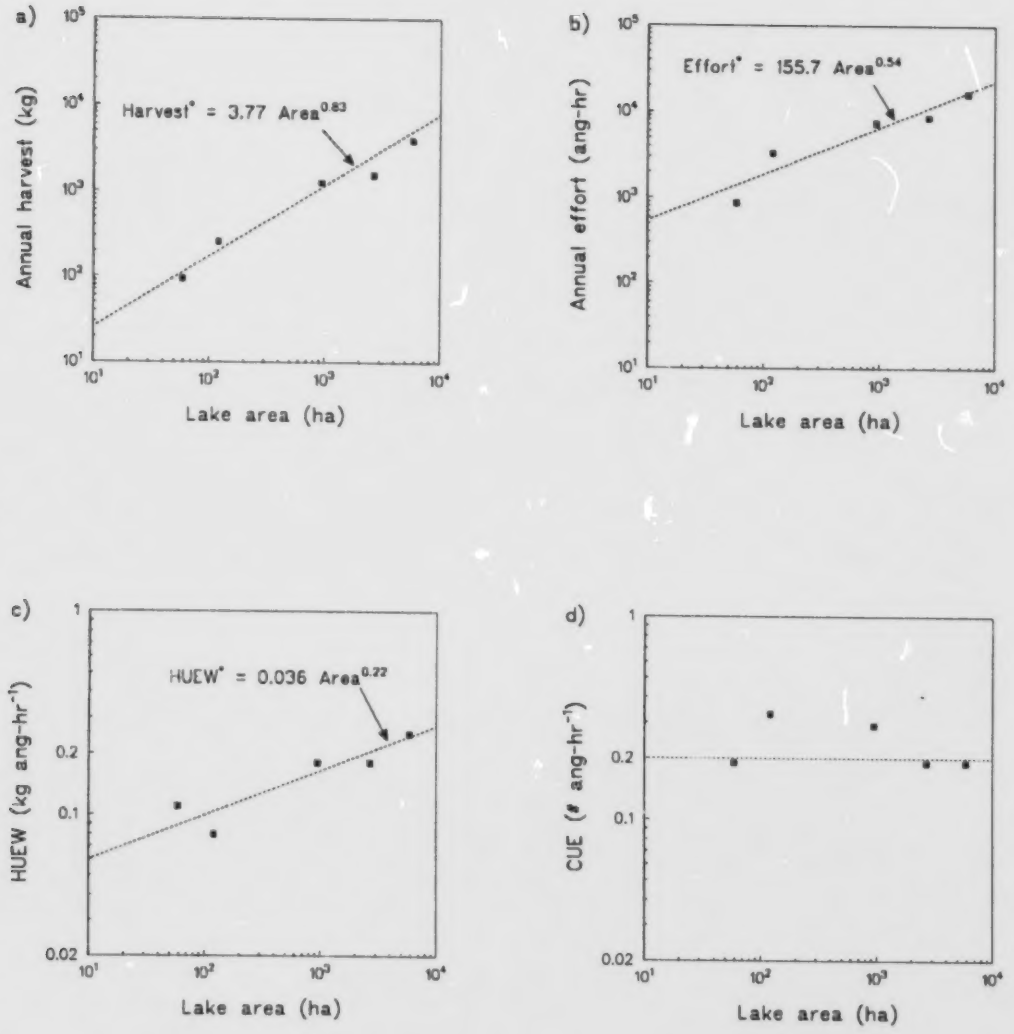


FIG. 3. Lake area relationships for maximum sustainable lake trout harvest and the values of effort, HUEW and CUE under maximum sustainable harvest conditions. Data from Payne et al. (1990).

giving estimates of 0.10, 0.17 and 0.27 kg ang-hr^{-1} for lakes of 100, 1000 and 10000 ha. This effect is largely due to a change in fish weight with lake area. CUE, an index of numerical abundance, is not significantly related to lake area (see Fig. 3d). The CUE estimates assumed that anglers did not release fish (data not available) and were calculated as HUEW divided by the mean weight of harvested fish. Although the results are variable and a complex relationship may exist, **we recommend a fixed CUE of 0.20 fish ang-hr^{-1} be used as a reference value**. This is the approximate minimum value observed in these five lakes.

Figs. 4 and 5 demonstrate how these criteria could be used to classify lakes. Historical estimates of annual lake trout effort, HUEW and CUE are shown in Fig. 4 for 78 Ontario lakes with self-sustaining lake trout populations. The criteria defined above are shown as a dotted line in each graph. The location of each point with respect to this line allows lakes to be classified as high or low with respect to effort and abundance criteria.

Classifications based on any single variable are of limited value, but the combination of effort and abundance criteria classifies lakes into development stages defined above. This is illustrated in Fig. 5 where the ratio of assessed value to reference value for abundance (HUEW and CUE) is plotted against the same ratio for effort. The lines drawn where these ratios equal one (i.e. assessed value = reference value) divide the graph into four quadrats which correspond to the four development stages described in Fig. 3b. **The location of a lake on this graph therefore identifies its stage of development and the overall status of lake trout could be described by calculating the proportion of lakes in each stage.** From these data, one would judge that a problem exists because abundance is low in a large proportion of lakes (Stages III and IV).

This example demonstrates an approach promoted in this paper for evaluating the status of lake trout in Ontario lakes. Important components are summarized as follows. **First, time series studies of FAU**

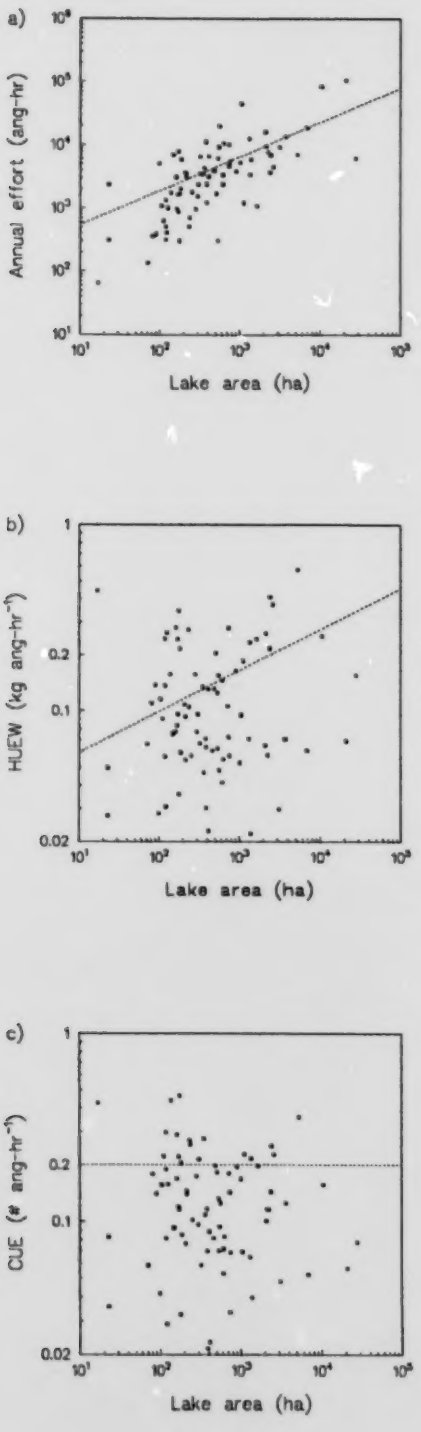


FIG. 4. Demonstration of how effort and abundance criteria can be used to classify lakes. Historical estimates of annual lake trout effort (a), HUEW (b) and CUE (c) from Ontario lakes are plotted against lake area. Dotted lines are the relationships determined in Fig. 3.

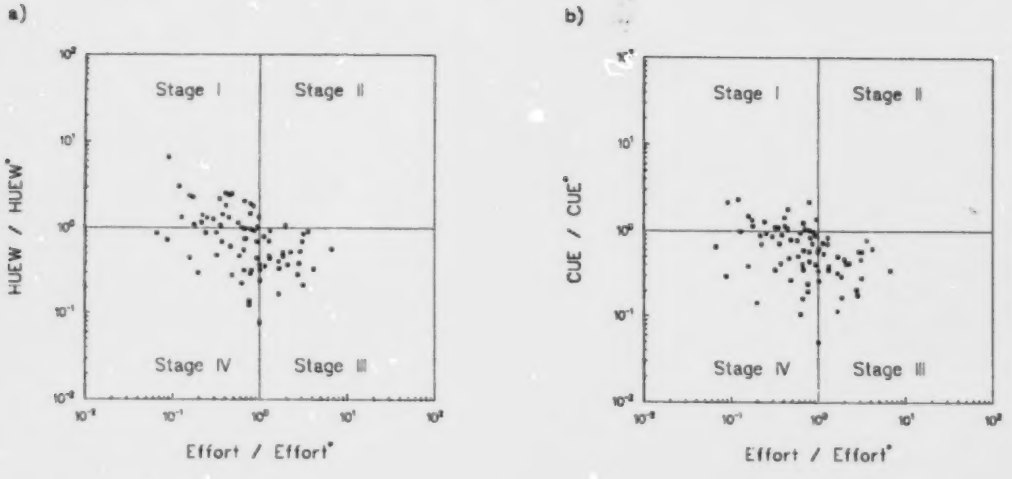


FIG. 5. Demonstration of how data shown in Fig. 4 can be used to classify lakes into stages of development. See text for details.

lakes are needed to define relationships between maximum sustainable harvest, corresponding levels of effort and abundance, and intrinsic lake variables. Such relationships supply criteria (i.e reference values) for evaluating district lakes. The criteria proposed above are based on a sample of only 5 lakes and must be viewed as tentative. A much larger sample is needed to better define the effect of lake area and to identify the role of other factors (e.g. lake morphometry, nutrients). Criteria should be updated as more harvest, effort and abundance data become available from FAU lakes.

Second, relatively large numbers of district lakes must be assessed to perform an extensive evaluation of lake trout status. This can be done at relatively low cost because harvest assessment is not required. Only effort and abundance information are needed to classify lakes in the manner described above (Fig. 5). Abundance assessment is not considered a problem because a single season of sampling supplies the required data. Angling or index fishing indices of abundance could be used, providing FAU data are available to account for season and gear related differences in catchability. Effort

assessment is more expensive because an annual estimate is needed. Techniques for reducing effort sampling costs are described below following a general discussion of measurement issues.

MEASUREMENT ISSUES

Production models developed from harvest and effort data assume that effort is measured in units proportional to fishing mortality and that harvest accounts fully for deaths due to fishing. It is important, therefore, to consider what units are appropriate for measuring effort and the extent to which harvest may underestimate its impact. Problems arise when assessing a sport fishery because the impact of fishing is affected by various factors including catch-and-release practices, seasonal differences in catchability and variation in party size and number of rods per angler. These issues are addressed in proposing standards for reporting of harvest, effort, and abundance data. The standards are relevant to both the FAU and district lake sampling programs, with the exception of harvest which is not estimated on district lakes.

Harvest as an Estimate of Killed Weight

Harvest will underestimate the impact of fishing if anglers release fish and some of these fish die as result of being captured. Historically, this has not presented a problem because anglers have harvested most of the lake trout they've caught. Harvest proportions for lake trout have typically been greater than 90% (Fig. 6). Problems are likely to arise in the future, however, given current management practices that promote catch-and-release fishing and apply various forms of catch restrictions (e.g. slot size, minimum size, one over maximum).

The bias that results when harvest is used as an estimate of killed weight depends on the proportion of the catch harvested (P_h), the proportion of released fish that die due to capture (P_d) and differences in the mean weights of harvested and released fish. The bias in terms of number of fish (i.e. ignoring mean weight differences) can be expressed as the ratio of the number harvested to the total number killed and calculated as

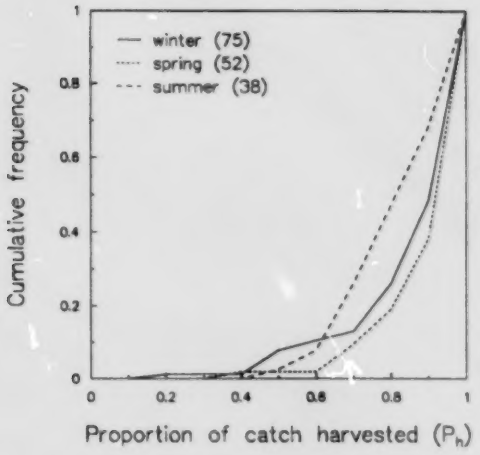


FIG. 6. Cumulative frequency distribution of P_h, the proportion of the lake trout catch that is harvested. Results are based on 76 winter, 52 spring and 38 summer surveys. Means (and standard deviations) of P_h are: Winter - 0.84 (0.17); Spring - 0.90 (0.13); Summer - 0.81 (0.16).

$$\frac{\textit{No. harvested}}{\textit{No. killed}} = \frac{P_h}{P_d + (1 - P_d)\,P_h} \qquad [3]$$

Given a study by Loftus et al. (1988) which estimated post-release mortality in lake trout at 15% (i.e. P_d = 0.15), we calculated the bias expected for a range of harvest proportion values (Fig. 7). The graph indicates that historical bias has been very small: when greater than 90% of the catch is harvested, harvest accounts for greater than 98% of the total kill. An appreciable bias does not arise until P_h values are very small.

We conclude that unless dramatic changes occur in catch-and-release tendencies, harvest supplies a sufficient estimate of the impact of fishing. **Estimates of harvest should always be accompanied by estimates of the harvest proportion so that a potential bias can be evaluated. These estimates**

should be reported by season, in case release mortality varies among seasons. Seasonal reporting of P_h is also needed to measure effort in units that reflect its impact on the fish population (see below).

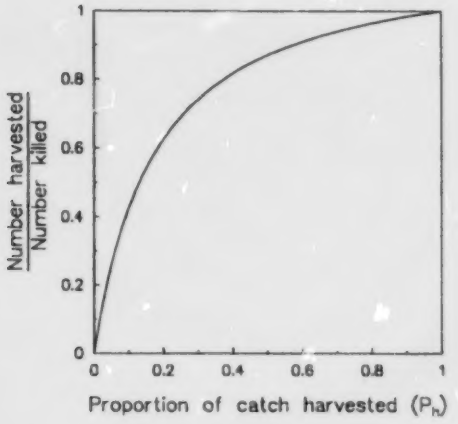


FIG. 7. The ratio of number harvested to number killed as a function of the harvest proportion. The curve was generated from equation [3], given a release mortality (P_d) estimate of 0.15.

Effective Effort

For production modelling purposes, effort substitutes for fishing mortality rate and should be measured in units proportional to this rate. Effective effort is defined by Ricker (1975) as fishing effort adjusted, when necessary, so that each increase in the adjusted unit causes a proportional increase in the instantaneous rate of fishing mortality. Nominal scales of measurement are not appropriate. They must be adjusted to exclude effort that does not kill fish and to accomodate seasonal differences in catchability and other factors that influence angling effectiveness.

The following formula is proposed for calculating annual effective effort (f):

$$f = \sum_{j=1}^{n} E_j \; P_{e,j} \; P_{h,j} \; B_j \qquad [4]$$

where j identifies a season, E is effort in ang-hrs, P_e is the proportion of effort directed at lake trout, P_h is the harvest proportion, and B is a weighting factor that adjusts for seasonal variation in catchability. This equation ignores effort that is not targeted on lake trout because historical data (not shown) indicate that incidental harvest of lake trout is negligible, usually accounting for less than 1% of total harvest. The equation also adjusts effort by the proportion of the catch harvested (P_h) to exclude effort that does not kill fish (assuming post-release mortality is negligible). Weighting factors (B) are included because seasonal differences in catchability have been reported in various studies (Schumacher 1961, Olver 1988, Evans et al. 1991). Values of these factors can be determined empirically by comparing catch rates across seasons. Until this has been done, reporting of effective effort must assume B = 1 for each season.

One problem not addressed by this formula concerns factors that influence angler effectiveness (e.g. number of rods-per-angler, party size, use of a guide, type of gear including use of fish finders). Appendix B reports analyses done to investigate effects of rods per angler and party size. Winter fishing results indicated that number of rods has a variable effect on the rate of catching lake trout. On some lakes, anglers with two rods experienced higher catch rates; in other cases, the opposite effect was observed. The average effect was nil. For this reason, the formula proposed for calculating effective effort measures effort (E) in ang-hrs, not rod-hours.

Party size results reported in Appendix B indicate that catch-per-ang-hr decreases as party size increases. The relationship implies, for example, that one angler fishing for 10 h catches 1.4 times more fish than two anglers fishing together for 5 h. Christie (1984) reported similar results for walleye (*Stizostedion vitreum vitreum*) fishing. A formula for effective effort that accommodates party size effects could be developed,

but this is not currently necessary because mean party size (and the distribution of party size) varies little among lakes. This factor should still be monitored in case changes in mean party size occur. The same argument applies to other factors (e.g. mean rods-per-angler, use of guides, type of gear). They should be monitored so that their effects can be determined, but adjustments for these effects will be necessary only if variation exists over years and/or lakes.

Abundance Indices

Two measures are proposed for indexing lake trout abundance from angling data: targeted catch-per-unit-effort (CUE_s) and targeted harvest-weight-per-unit-effort ($HUEW_s$). They should be reported for specific seasons because catchability may vary. Both measures are calculated using data from anglers whose effort was directed at lake trout. Targeted CUE is defined as the number of fish caught (C_s) divided by ang-hrs of fishing directed at lake trout (E_s):

$$CUE_s = \frac{C_s}{E_s} \qquad [5]$$

where the subscript s signifies data from anglers targeting on lake trout. Targeted HUEW is defined as the weight of fish harvested divided by ang-hrs of fishing directed at lake trout that resulted in harvest (i.e. effective ang-hrs):

$$HUEW_s = \frac{H_s \bar{w}_s}{E_s P_h} \qquad [6]$$

where H_s is the number of fish harvested, $\bar{w}_s$ is the mean weight of harvested fish, E_s is ang-hrs and P_h is the harvest proportion. Because harvest (H_s) equals catch (C_s) times the harvest proportion (P_h), the latter index can also be expressed as

$$HUEW_s = CUE_s \bar{w}_s \qquad [7]$$

The formula for $HUEW_s$ differs from traditional methods of calculating harvest rate (e.g. Lester and Trippel 1985) because it discounts effort by the harvest proportion. This adjustment is needed to obtain a meaningful index of lake trout abundance. If not applied, a change in the harvest proportion would by itself cause a change in the abundance index.

Index fishing offers an additional means of evaluating lake trout abundance. **The mean catch obtained from a standard fishing method supplies an abundance index which is expected to correlate with angling CUE. For lake trout assessment, this index must be obtained using the spring gillnetting methods described in Appendix A.** Comparable measures of abundance are not available if index fishing methods vary among lakes.

Recording of both angling and index fishing CUE on FAU lakes allows the calibration of these indices so that angling CUE values associated with maximum sustainable harvest could be transformed into index fishing measures of abundance. Index fishing could then be used as an alternative means of evaluating lake trout abundance. These criteria are not available because the proposed index fishing standards have not been widely applied on FAU lakes. Methods described for evaluating district lakes assume criteria will be available in the future.

ESTIMATING EFFORT ON DISTRICT LAKES

Traditional creel survey methods of estimating effort are expensive because they require a sampling domain that spans the entire fishing day. They are required on FAU lakes (see Sampling FAU Lakes), but not on district lakes. A shortcut method can be used to reduce sampling costs. The technique samples only during the middle portion of the fishing day, but uses data from FAU lakes to adjust for a bias that can result from this. The empirical basis of this method is described here and details about survey design are given in a subsequent section (see Sampling District Lakes).

The method, which we refer to as midday activity sampling, was suggested by Parker (1956) and promoted for surveys of Ontario lakes by Loftus (1984). They observed for winter fishing that activity during a day changes in a fairly predictable pattern. The number of angling parties present rises from low, early morning levels to high levels in the middle of the day and drops off later in the day. Although absolute levels of effort varied across lakes and day types, the percentage of effort expended during various times of the day was similar (Fig. 8). These observations suggested that a count made around noon could be multiplied by an empirically determined factor to estimate effort for the entire day.

We suggest this method be applied using a time window of 1000 to 1400 hrs for estimating midday means. The appropriate formula for estimating mean daily effort ($\bar{E}_d$) is

$$\bar{E}_d = \frac{MAC \; T}{K_m} \qquad [8]$$

where MAC is mean midday activity based on this time window, T is the length of the fishing day and K_m is the midday bias factor. The bias depends on whether mean midday activity differs from mean activity for the entire fishing day ($\bar{A}$) and is calculated as the ratio of these means:

$$K_m = \frac{MAC}{\bar{A}} \qquad [9]$$

Loftus' (1984) data from seven lakes (see Fig. 8) implies $K_m = 1.2$ for winter fishing. We analyzed a much larger set of data to test this result and estimate the bias parameter for other seasons (Fig. 9).

Daily patterns of fishing activity on individual lakes were examined by calculating mean activity for 2 hr periods of the fishing day and dividing each estimate by mean activity for the entire fishing day. Means of log transformed ratios were used to combine results across lakes. These means are plotted against time of day in Fig. 9. The graphs demonstrate how activity at various times of the day differs from the daily mean. Results are shown for different day types (weekday, weekend/holiday) within winter, spring and

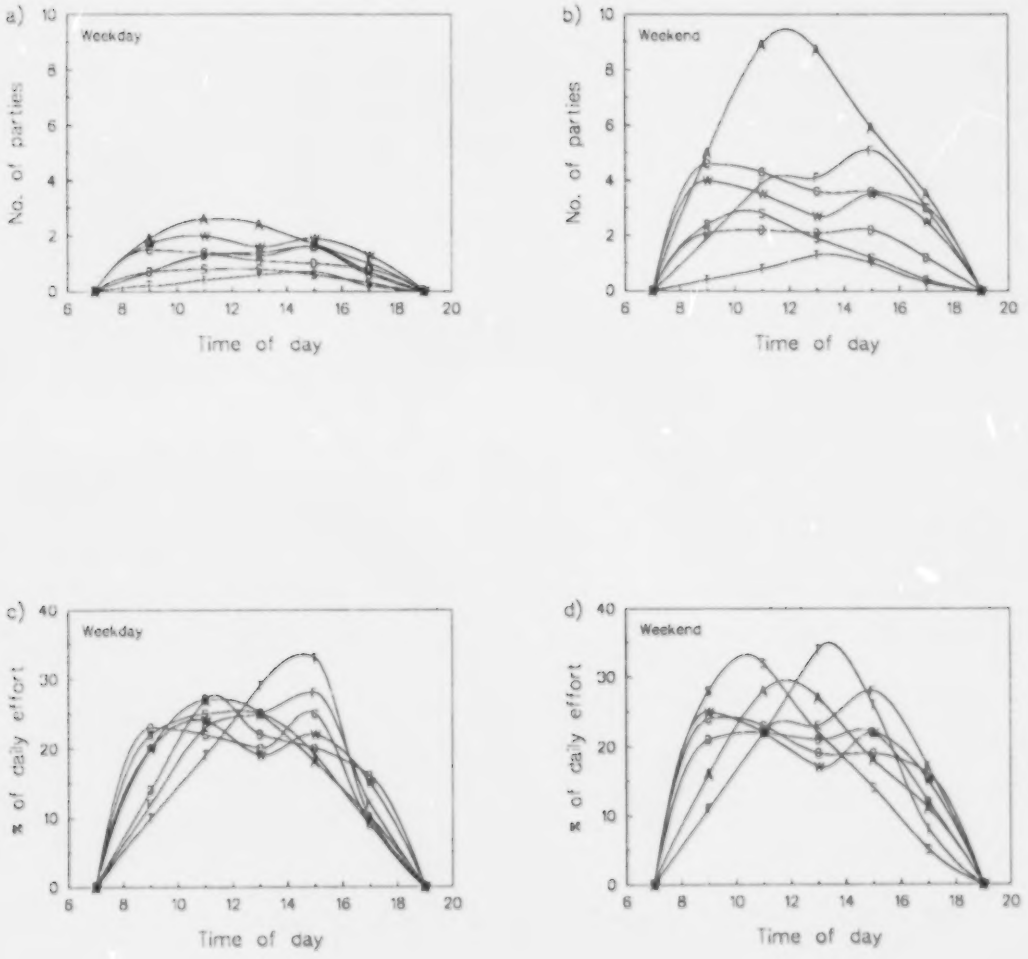


FIG. 8. Winter activity profiles from seven Ontario lakes, redrawn from Loftus (1984). Mean activity (# of parties) is plotted against time of day for weekdays (a) and weekends (b). In c) and d), the activity data are expressed as a percent of daily effort. Letters designate lakes: Anstruther (A), Chandos (C), Dickey (D), Faraday (F), Silent (S), Thanet (T), Wollaston (W). Surveys sample a 10 hr day (0800 - 1800 hrs).

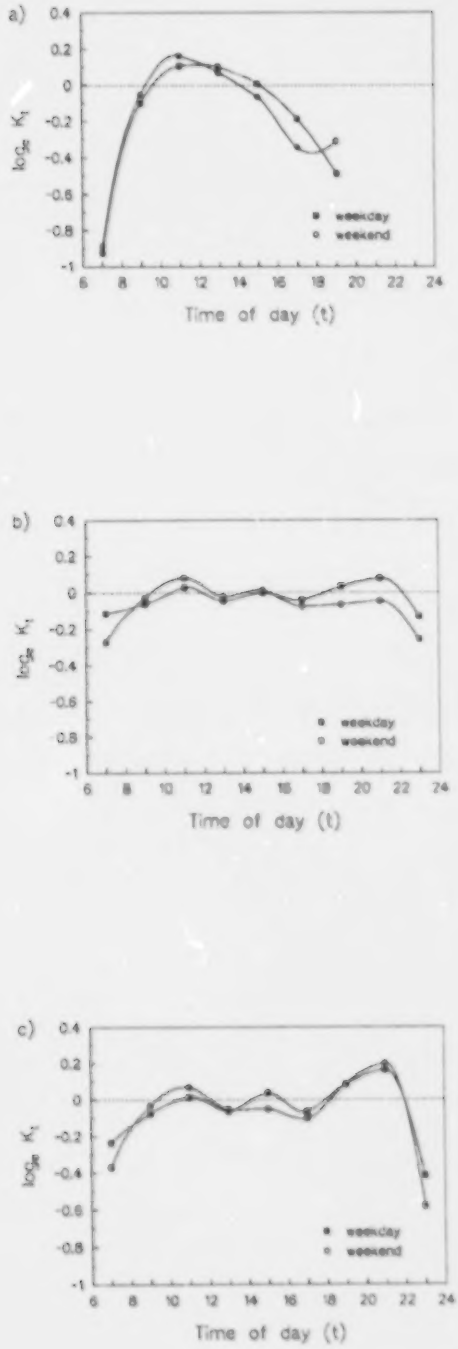


FIG. 9. Activity profiles for winter (a), spring (b) and summer (c) angling in Ontario lakes. K_t is mean activity for a period (t) of the day divided by mean activity for the whole day. The dotted line signifies activity is equal to the daily mean.

summer seasons. Fall season data were not available.

The winter results agree closely with findings from Loftus (1984). A midday peak is observed and the activity ratio averaged across 1000 - 1400 hrs implies $K_m = 1.2$. During the spring and summer, midday peaks are not observed midday activity levels are approximately equal to mean daily levels. This implies that spring and summer estimates of effort based on midday activity will not be biased (i.e. $K_m = 1$).

Given these estimates of bias factors and some additional parameters available from historical data, the following formula can be used to calculate effort from estimates of midday activity. Equation [8], which calculates mean daily effort, can be expanded to calculate effort for an entire season (E_j)

$$E_j = \frac{MAC_j \; T_j \; \bar{p}_j \; N_j}{K_{m,j}} \qquad [10]$$

where j identifies a season, $\bar{p}$ is mean party size and N is the number of fishing days in the season. Table 1 supplies seasonal values for bias factors (K_m), fishing day length (T) and mean party size ($\bar{p}$). The mean party size estimate (2 ang/party) is based on data shown in Appendix B.

Table 1. Parameter values for calculating effort from estimates of mean midday activity (MAC).

Season	Midday bias factor K_m	Fishing day length T	Mean party size $\bar{p}$	Harvest proportion (lake trout) P_h	Effort proportion (lake trout) P_e	Season weighting factor B
Winter	1.2	10	2	0.84	1.0	1.0
Spring	1.0	14	2	0.90	1.0	1.0
Summer	1.0	14	2	0.81	1.0	1.0

Table 1 also supplies values of the following parameters required by equation [4] to calculate annual effective effort (f) from seasonal estimates of total effort (E_j): harvest proportion (P_h), the proportion of effort

directed at lake trout (P_e) and seasonal catchability weighting factors (B). Values assigned for P_h are seasonal averages for the data summarized in Fig. 6. Values for other parameters (P_e, B) have not been determined and are assigned a value of one. Estimates for P_e could be obtained from historical data and we suggest these be determined for different fish community types. Fish community type is expected to be an important determinant of P_e because it identifies sport fish species that exist in a lake (OMNR 1978). More accurate estimates of effort could be obtained if all of these parameters were determined on a regional basis. **We recommend that data from FAU lakes within each region be used to supply estimates of K_m, T, β, P_h, P_e and B.** More extensive analyses are needed to do so.

MORTALITY, GROWTH, AND CONDITION

Mortality, growth, and condition are three additional variables that could be used to evaluate the status of lake trout in district lakes. Here, we define these variables and propose some reference values for evaluating district lakes. The proposed criteria are based on a small sample of lakes and more time series monitoring of these variables on FAU lakes are needed to develop better diagnostic criteria. Sampling problems are discussed and we recommend standards for FAU lake assessment. We also address the assessment cost issue and develop some cheap methods for evaluating these variables on district lakes.

CRITERIA FOR EVALUATING DISTRICT LAKES

Mortality

Total mortality is the number of fish removed from the exploitable population due to deaths resulting from natural causes (i.e. predation, disease) and fishing. Its value can be expressed as an instantaneous rate (Z, the probability of dying during a small unit of time) or an annual rate (A, the proportion of the population that dies during one year). These are related by the equation:

$$A = 1 - e^{-Z} \qquad [11]$$

Total mortality can be partitioned into natural and fishing mortality rates that describe relative contributions of different causes of death. Estimation of these separate components (see Pauly 1984) is more difficult

than estimating total mortality, because it requires either that time series estimates of total mortality and fishing effort are available or that tagging studies are done. This partitioning is not necessary to evaluate conditions in district lakes because total mortality is the critical variable of interest.

Lake trout mortality rates, estimated under maxiumum sustainable harvest conditions, are shown in Fig. 10 for the five lakes used to establish effort and abundance criteria in Fig. 3. Except for one lake, mortality is fairly constant at a mean rate (Z = 0.71) implying 51% annual mortality. This rate is much higher than estimates predicted by a production model developed by Payne et al. (1990). Their model expects rates around 30%, ranging from 26% to 33% as lake area increases from 100 to 10000 ha. The single result well predicted by their model is the lowest value shown in Fig. 10 (Lake Opeongo, A = 30%).

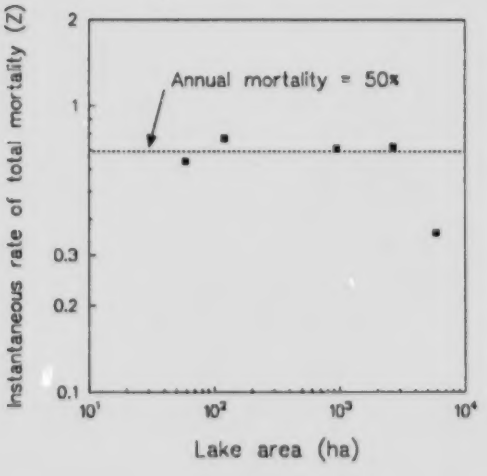


FIG. 10. Lake trout total mortality rates (Z), estimated under maximum sustainable harvest conditions, plotted against lake area. The dotted line indicates 50% annual mortality (Z = .69). Data from Payne et al. (1990).

Payne et al. (1990) acknowledged that their model was based on limited data and for this reason ignored the model results when suggesting criteria for diagnosing populations. They state that populations

experiencing total mortality of 50% (Z= 0.7) are almost certainly overexploited. **We recommend that a total annual mortality of 50% (Z = 0.7) be used to classify district lakes and that this value be interpreted as a maximum acceptable level of mortality**. On many lakes, it probably exceeds the value resulting in a maximum sustainable harvest. We also recommend that a length statistic (mean length above 400 mm) be used as a low cost method of evaluating mortality on district lakes. The empirical basis of this method is discussed below (see p. 38).

Growth

The commonly used formulation for growth is the von Bertalanffy growth equation

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right) \qquad [12]$$

where:

- L_t is the expected fork length of fish at age t;
- L_∞ (asymptotic length parameter) represents the fork length at age infinity;
- K (growth rate parameter) represents the fraction by which the gap between L_t and L_∞ is closed each year; and
- t_0 is a parameter representing the theoretical age at which fish length is zero.

This formula predicts annual increments in length that decrease with age as fish approach an asymptotic (maximum) length. Growth parameters can be estimated for individual cohorts (year-classes) so that changes in growth over time can be studied in detail. Alternatively, the mean length of different cohorts at a point in time can be used to characterize growth for the population as a whole. The latter approach is sufficient when the purpose is to compare growth in different lakes or the same lake at widely separated points in time.

Growth is a potentially useful indicator of population status because it responds readily to changes in abundance and, therefore, tends to increase as exploitation increases. These effects are confounded by physical (primarily thermal) and chemical properties of lakes, as well as biological properties relating to the availability of food. Variability in growth properties of Ontario lake trout populations has been described

by Payne et al. (1990). Asymptotic length (L_∞) ranges from approximately 400 to 1200 mm, with higher growth being observed in larger lakes.

Growth criteria for evaluating district lakes could be based on characteristics expected under maximum sustainable harvest conditions. Because growth is a second order response (see Evans et al. 1990), abundance of lake trout under maximum harvest conditions should dictate a particular form of growth which could be characterized by asymptotic length (L_∞). High growth, indicated by an assessed value of L_∞ that exceeds this criterion, would then be interpreted as a sign of overexploitation (i.e low abundance) and vice versa. Sufficient data are not available to identify growth criteria in the above manner. As an alternative, **we recommend that the following growth relationship (from Payne et al. 1990) be used to evaluate district lakes**:

$$L_\infty = 290 + 107 \log_{10} Area \qquad [13]$$

The equation states that asymptotic length (mm) increases with lake area (Fig. 11a), implying values of 504, 611, and 718 mm for lakes of 100, 1000 and 10000 ha. Although the growth rate parameter (K) is

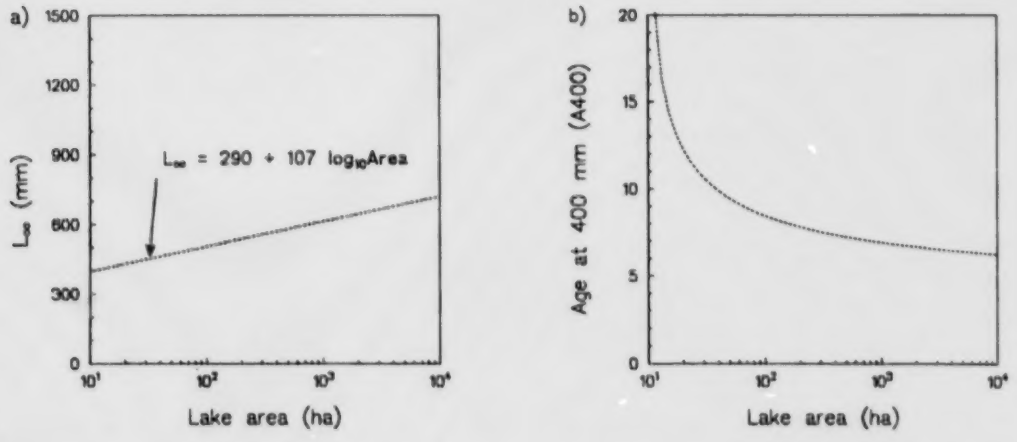


FIG. 11. Criteria for evaluating growth in terms of a) asymptotic length (L_∞) and b) age at 400 mm (A400). The relationship with lake area in (a) was reported by Payne et al. (1990).

also correlated with area, this is mainly the effect of its correlation with L_∞ (Gallucci and Quinn 1979). For this reason, growth comparisons based on a single parameter are considered sufficient. We also suggest that a growth index, called age at 400 mm (A400), can be used to determine approximately how asymptotic length deviates from a reference value. This supplies a low cost method of evaluating growth which is suitable for district lake assessment. We later discuss its empirical basis and show how reference values for A400 (Fig. 11b) are implied by its relationship with L_∞.

Condition

The relationship between weight (w) and length (L) defines the condition of a fish population and can be expressed as

$$w = aL^b \qquad [14]$$

where a and b are referred to simply as weight-length parameters. Condition indices of various types (Fulton's condition factor, relative condition factor, relative weight), which convert this relationship into a single statistic, have been widely used in fishery science. Their use is not recommended because they result in a loss of information and, in many cases, an inaccurate representation of the relationship (see Bolger and Connolly 1989; Cone 1989;).

Condition is a consequence of both genetic properties and nutrition. Factors that influence food availability will be expressed in this relationship. If the amount (or quality) of food available per fish decreases, condition will deteriorate; if it increases, condition will improve. Changes in lake trout condition are expected therefore as a consequence of shifts in abundance, which alter competition for food.

Payne et al. (1990) used data from 23 Ontario lakes to develop the following weight-length standard for Ontario lake trout:

$$w = 3.88 \times 10^{-6} L^{3.18} \qquad [15]$$

Analyses were unable to detect effects due to several lake variables (including surface area) and the lack of quantitative measures of stress prevented any analysis for stress effects. Pending additional information about factors that influence the weight-length relationships in lake trout, **we recommend that equation [15] be used as a reference for classifying lake trout populations.**

SAMPLING PROBLEMS

Age Determination

Biased estimates of mortality and growth can result from errors in determining ages of fish. This is a particular problem in slow growing species such as lake trout. Although scales have been widely used to estimate the age of lake trout, scale determined ages differ from ages implied by other bony parts such as otoliths, branchiostegal rays, fin rays, cleithra, vertebrae, and opercular bones (Bulkley 1960; Dubois and Lagueux 1968; Johnson 1976; Power 1978; Martin and Olver 1980; Casselman 1983; Hoyle and MacLean 1988; Sharp and Bernard 1988). Ages from all structures are similar for young fish, but most structures underestimate the age of mature fish. Otoliths offer the most reliable age estimates, but they are difficult to collect (given the surgical procedure required) and also necessitate killing of fish.

Based on these studies and unpublished data (J. Casselman, OMNR, L. Ontario Fish. Res. Station, Glenora, Ont. K0K 2T0), **we recommend that 7 yrs be treated as the maximum age determined reliably from scales**. Otolith assessment is needed to assign ages for fish greater than 7 yrs. Scale samples should be obtained from all fish, but unnecessary killing of fish must be avoided and otoliths should be collected only when sampling dead fish. Sampling of angler catch will be the main source of otolith data because the index fishing methods proposed in this paper are designed to avoid mortality.

The data needed to estimate mortality and growth are hard to obtain when a non-destructive sampling rule applies. Intensive sampling of the sport fishery on FAU lakes is expected to provide an adequate sample of otoliths, but sufficient sample sizes are not expected on district lakes where less intensive sampling will

apply. For this reason, we have developed some approximate methods of evaluating mortality and growth that can be applied when only scale age data are available (see Growth Index and Mortality Index). Long-term solutions to this problem may lie in the area of length-based assessment methods (Jones 1984; Schnute 1987; Schnute et al. 1989a, b).

Size Selectivity

Sampling of fish captured by angling or index fishing obtains a biased sample of the fish population because fishing methods are selective for certain sizes of fish. Selectivity varies depending on the type of gear used, the type of habitat sampled and the time of year when sampling occurs. The same gear might be used to sample the same habitat in different seasons of the year, but it is likely to yield different results because the spatial distribution of fish varies over time.

Examples of how size selective properties of fishing gear can bias estimates of mortality and growth are given in Appendix C. The appendix also describes methods of studying size selectivity and presents some results for angling and gillnetting gear. The angling results suggest that medium sized lake trout are most vulnerable. Although this finding is based on very little data, similar results have been reported for walleye (Ryan 1989). Gillnet selectivity, estimated for mixed mesh gear employed by the Lake Ontario FAU, indicates that capture efficiency increases with fish length, the largest fish being the most vulnerable.

The magnitude of biases that can result for estimates of mortality (and growth to a lesser extent) warrants that length selection curves be developed to supply correction factors for estimating these parameters. Results shown in Appendix C merely indicate that a problem exists. A wider based examination of the problem is needed to allow better interpretation of angler and index fishing catches. The necessary data are available when fall tagging of lake trout is done. Recapture rates of different sizes of marked fish can then be used to estimate size selectivity. We recommend this procedure on a sample of FAU lakes to document seasonal differences in angling selectivity and estimate selectivity of the spring index fishing

method described in Appendix A. Methods described below for estimating mortality and growth ignore size selectivity problems and are expected to yield biased results.

Bias due to selectivity is further complicated by selective harvesting of fish. This results partly because fishermen have preferences for keeping certain sizes of fish, but also because some fishing regulations (e.g. minimum size, slot limit, one over maximum) impose selective harvesting. The issue could be avoided by sampling released fish as well as harvested fish, but this requires special arrangements with anglers (e.g. angler diaries) because released fish are not available at the time of sampling. Length data for a sample of released fish is an important requirement that should apply whenever a significant portion of the catch is released.

ASSESSMENT OF FAU LAKES

Estimates of mortality, growth and condition parameters on FAU lakes are needed to identify better criteria for evaluating district lakes. Standard methods are proposed below. The required length, weight and age data can be obtained by sampling angler catch when conducting creel surveys (in each season) to estimate harvest, effort, and abundance. Spring index fishing provides an additional data source. For each variable, we describe analytical methods and suggest what pooling of data (among seasons and fishing method) could be done to deal with sample size problems.

Mortality

In ideal situations, mortality rate is implied by the age structure of the catch and can be estimated using catch curve methods (reviewed by Ricker 1975). The proportion of fish in each age group is plotted (on a logarithmic scale) against age, and the slope of the right arm provides an estimate of the instantaneous mortality rate (Z). This method involves the following assumptions about age groups (in the right arm):

- mortality rate is the same for all ages;
- mortality rate has been constant over time;

- each age group was recruited with the same abundance (or recruitment variation was small and random in nature);
- each age group is equally vulnerable to the gear;
- sample size is sufficiently large to effectively represent the average population structure; and
- ages are reliably determined.

Ricker (1975) discusses and provides examples for most of these sources of bias.

Some of the above problems can be avoided by comparing the abundance of individual year-classes in successive years. Such data are available from FAU lakes where the core data program has been implemented. The method requires two successive years of age specific CUE data. It calculates age specific mortality rates and controls for variation in recruitment, gear selectivity and changes in mortality over time (Fig. 12). Survival (S) can be calculated for each age group as the ratio of CUE in the second year to CUE in the first year and plotted against age. If mortality is constant for all ages, the expected result is a horizontal line (slope = 0) and the average value of survival supplies an estimate of annual mortality (A = 1 - S). If mortality varies with age, these points could be fitted using a suitable mathematical function and age specific mortality rate would be described in terms of this function.

As in the case of catch curve fitting, this method must focus on older fish that are fully recruited. Survival estimates for young fish may be greater than 1.0 because they have not attained a size that results in maximum catchability. These age groups must be excluded when estimating mortality. Reporting of estimates should identify the minimum age included in the analysis.

The successive year method of estimating mortality should be applied independently for each combination of fishing method and season data that are available. Similar results are expected if gear selectivity is not a major problem. A pooled estimate could also be obtained that combines CUE ratios from index fishing and each season of angling.

ESTIMATING SURVIVAL FROM AGE COMPOSITION OBSERVED IN ONE YEAR

ASSUMPTIONS:

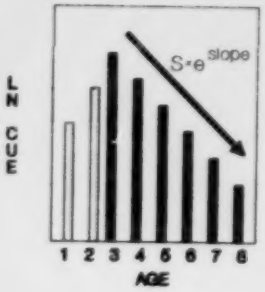
1. All age groups are recruited with the same initial abundance.

2. Survival may vary between ages but each age specific survival remains constant over time.

ALTERNATIVELY WE CAN ASSUME:

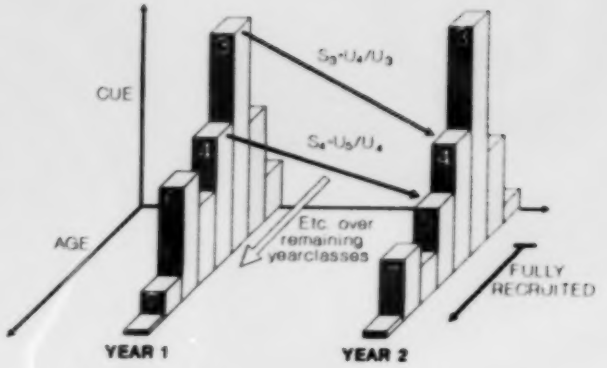
1. Recruitment fluctuates (but there is no overall upward or downward trend).

2. Survival is the same over a range of ages, and also remains constant over time.



ESTIMATING SURVIVAL FROM AGE COMPOSITION OBSERVED IN TWO SUCCESSIVE YEARS

ASSUMPTIONS (1) and (2) CAN BE AVOIDED BY COMPARING ABUNDANCES OF THE SAME COHORT IN TWO SUCCESSIVE YEARS:



BOTH METHODS FURTHER ASSUME THAT:

3. Each age group is equally vulnerable to the gear
4. Ages are reliably determined
5. Sample size is sufficiently large to effectively represent the average population structure.

FIG. 12. Comparison of single year and successive year methods of estimating total mortality.

Growth

Non-linear regression methods are needed to estimate von Bertalanffy growth parameters (eq. [12]) from length at age data. This technique has stringent data requirements. Poor fits and unreliable estimates of parameters can result for a number of reasons including:

- inadequate sample sizes, especially for older fish;
- age determination errors, especially for older fish;
- bias due to size selectivity;
- bias (and variance) due to growth within a year; and
- the shape of the growth curve is not described by the von Bertalanffy growth equation.

Effects of these factors on estimates of growth parameters were discussed by Payne et al. (1990). They argued that fitting an equation to estimate three parameters is not appropriate when data are subject to these inadequacies, and they devised an alternative method to approximate von Bertalanffy parameters. Their method was developed to work around problems existing in historical data. A better solution can result by addressing these problems when identifying data requirements for estimating growth.

Some problems can be avoided. Age determination errors can be largely eliminated by rejecting data from scale aged fish when the scale implies an age greater than 7 yrs. Data from otolith aged fish only should be used to examine the growth of older age groups. Problems due to growth within a year can be avoided by using data from winter and spring seasons, before rapid growth occurs.

The size selectivity problem cannot be avoided and may result in different estimates of growth, depending on whether fish were obtained by angling or index fishing. The extent of the problem could be evaluated by comparing these results. If the difference is large, it is important that growth characteristics be reported separately for each type of data. Otherwise, pooling of angling and index fishing data is acceptable and

would be recommended in order to obtain a larger sample size for estimating growth. Pooling the winter and spring data from two consecutive years of study is also an acceptable means of increasing the sample size.

When regression is done to estimate parameters, the growth curve should be forced through the origin. This constraint ($t_0 = 0$) is expected to result in more reliable estimates of K and L_∞. It is based on the assumption that t_0 is a species specific parameter. Although its "true" value for lake trout may deviate slightly from zero, this approximation will have a small effect on estimates of K and L_∞. On the other hand, if t_0 is not fixed, estimates of t_0 will vary and this can have substantial effects on K and L_∞ estimates.

Condition

Condition parameters can be estimated using linear regression methods to fit the logarithmically transformed weight-length relationship:

$$\log_{10} w = \log_{10} a + b \log_{10} L \qquad [16]$$

Functional regression of weight-length observations from individual fish should be used because both variates (weight and length) are subject to measurement error (Ricker 1973, Jensen 1986).

Because food availability and gonadal weight are seasonally dependent, the relationship is expected to vary among seasons and should be reported by season. Pooling of spring angling and index fishing data is acceptable because bias due to gear selectivity is not expected.

ASSESSMENT OF DISTRICT LAKES

Methods of evaluating mortality, growth and condition on district lakes assume a single season and year of sampling and a relatively small sample size. Condition parameters can be estimated using the method described for FAU lakes (eq. [15]). Different methods are proposed for evaluating mortality and growth because it is not expected that an adequate sample of otolith aged fish will be obtained. These methods

are based on an empirical growth model determined from 12 lake trout populations that were aged from otolith data. Growth assessment is described first because mortality assessment requires an index of growth.

Growth Index: Age at 400 mm

Growth characteristics of a lake trout population can be approximated by a simple index that reports expected age at a given length. The index is referred to as age at 400 mm (A400) because a fork length of 400 mm is chosen for estimating this age. Some growth data are presented to demonstrate what values of A400 are expected for Ontario lake trout populations, how this index is related to growth parameters, and how it should be estimated.

Estimates of growth parameters for 12 lake trout populations are shown in Fig. 13a (data from Payne et al. 1990). The regression line

$$K = \frac{94.1}{L_\infty} \qquad [17]$$

indicates that K is inversely related to L_∞ and that an approximate growth model for lake trout could treat the product of these parameters as a constant (see Gallucci and Quinn 1978). Growth curves generated by this empirical model are shown in Fig. 13b. They do not overlap, except at very young ages, and therefore indicate that growth parameters could be approximated from a single point on the curve.

Expected age at 400 mm (A400) decreases from approximately 10 to 5 yr as L_∞ increases from 450 to 1250 mm. The relationship is described by solving the von Bertalanffy equation for t (i.e. age),

$$t = t_0 - \frac{1}{K} \log_e\left(1 - \frac{L_t}{L_\infty}\right) \qquad [18]$$

substituting equation [17] for K, and setting $t_0 = 0$ (because this constraint was applied when estimating

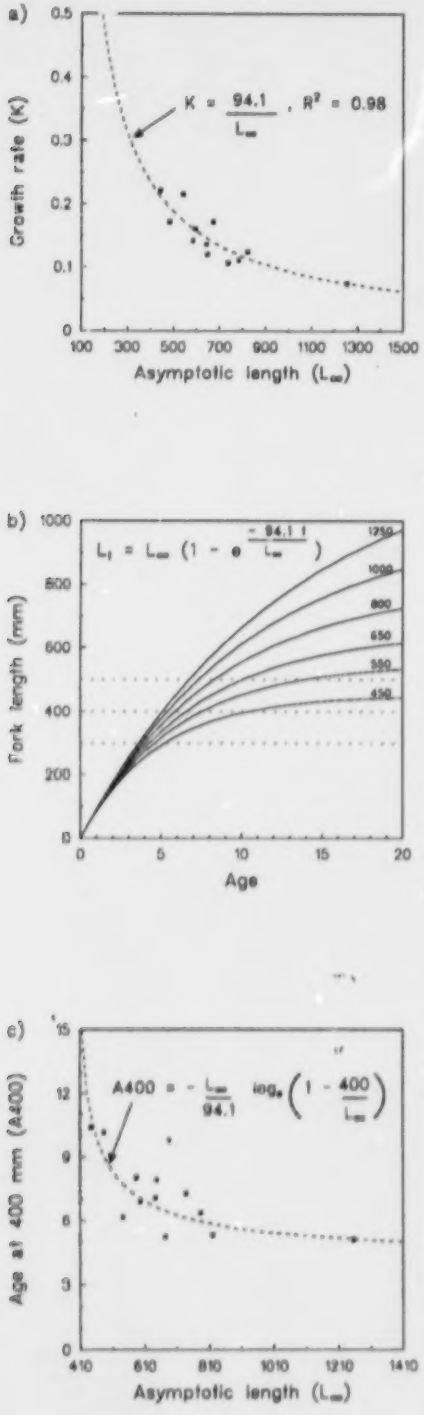


FIG. 13. Empirical basis of a lake trout growth index. In a), the relationship between K and L_∞ is shown. Parameters estimated for ages > 3 yrs and $t_0 = 0$. Data from Payne et al. (1990). In b), growth curves generated by this relationship are shown. In c), the implied relationship between age at 400 mm (A400) and L_∞ is shown. Points are estimates obtained for data shown in a).

K and L_∞):

$$t = -\frac{L_\infty}{94.1}\log_e\left(1 - \frac{L_t}{L_\infty}\right) \qquad [19]$$

Because A400 is defined as the value of t when L_t = 400 mm, the implied relationship is

$$A400 = -\frac{L_\infty}{94.1}\log_e\left(1 - \frac{400}{L_\infty}\right) \qquad [20]$$

This relationship is illustrated in Fig. 13c. A400 estimates for the 12 populations (shown in Fig. 13a) are also shown. They indicate that although A400 will not supply precise estimates of L_∞ on individual lakes, the index is not biased.

As shown in Fig. 11a, the criteria proposed for evaluating growth are based on a L_∞ - lake area relationship reported by Payne et al. (1990). This relationship can be expressed in terms of a growth index by substituting equation [13] for L_∞ in equation [20]. This produces an inverse relationship (Fig. 11b) in which A400 decreases from 8.5 to 6 yr as lake area increases from 100 to 10000 ha. A400 estimates obtained for a set of lakes could be shown on this type of graph to evaluate lake trout growth. Points lying below the reference line signify high growth (i.e. high L_∞) and, thus, a large proportion of points in the upper region would indicate that lake trout abundance may be low.

A400 should be estimated from a restricted fork length range (300 - 500 mm) in order to reduce a scale ageing bias. Regression of scale age versus fork length should be done to estimate parameters in equation [18]. A400 could then be calculated by setting L_t = 400 and solving for t. (Growth parameters (L_∞, K, t_0) estimated from this restricted size range must not be misinterpreted as population parameters; they are used only to estimate A400.) This technique does not eliminate a scale age bias because fish

older than 7 yr will exist within this size range. Scale bias will be small when L_∞ is high (i.e. > 800 mm) because fish reach a length of 500 mm at a relatively young age (see Fig. 13b). A400 will be underestimated when L_∞ is small because ages greater than 7 yr will exist within the 300 - 500 mm length range.

Mortality Index: Mean Length Above 400 mm

Although a catch curve is the best method of estimating mortality from point in time data, the method should not be used for lake trout when age is determined from scales. Mortality estimates would be high because scales underestimate the age of older fish. The alternative method described here uses a mean length statistic as a growth dependent index of mortality.

If growth characteristics did not vary among populations, mean length would be correlated with mean age. A high mortality (which results in a small mean age) would be indicated, therefore, by a small mean length. Similarly, a large mean length would indicate low mortality. The relationship is given by the formula (Beverton and Holt 1956)

$$Z = \frac{K\left(L_\infty - \bar{L}\right)}{\left(\bar{L} - L'\right)} \qquad [21]$$

where Z is the instantaneous rate of mortality, K and L_∞ are growth parameters, L' is a length not smaller than the smallest length of fish fully represented in the catch, and $\bar{L}$ is the mean length of fish greater than or equal to L'. We suggest a value of 400 mm for L' and therefore refer to $\bar{L}$ as mean length above 400 mm (ML400). Equation [21] can be restated as

$$ML400 = \frac{400\,Z + K L_\infty}{Z + K} \qquad [22]$$

Fig. 14a demonstrates how ML400 and L_∞ could be used to determine whether mortality exceeds a 50% guideline. For 12 populations whose growth parameters are shown in Fig. 13a, we calculated ML400 using equation [22] and setting Z = .693 (i.e. A = 50%). These results are plotted against asymptotic length in Fig. 14a. The relationship predicted by the empirical growth model is also shown. This was obtained using equation [17] to substitute for K in equation [22]

$$ML400 = \frac{400\,Z + 94.1}{Z + \frac{94.1}{L_\infty}} \qquad [23]$$

At 50% mortality, ML400 ranges from values slightly greater than 400 mm (when L_∞ is low) to around 480 mm (when L_∞ is high). Values greater than 480 imply low mortality in all populations, but mortality rates implied by smaller values of ML400 depend on the value of L_∞.

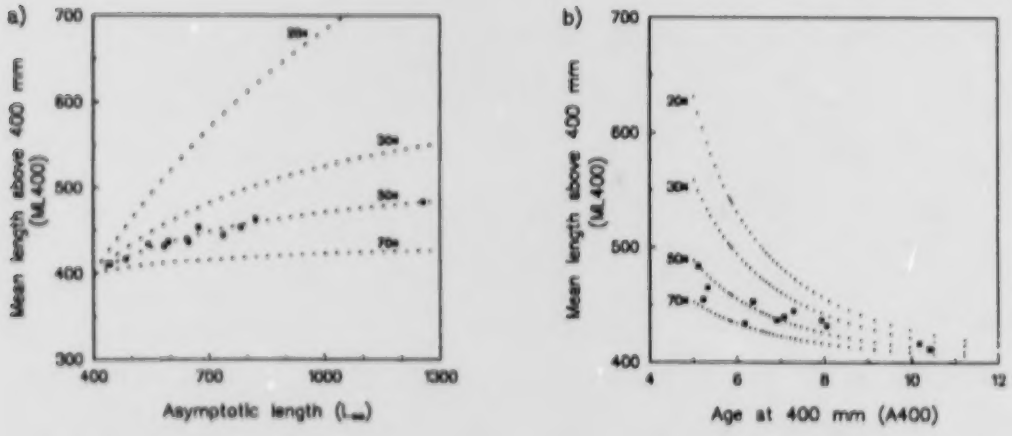


FIG. 14. Mean length above 400 mm (ML400) as an index of mortality. In a), the expected relationship between ML400 and L_∞ is shown for annual mortality rates of 20% (Z=0.22), 30% (Z=0.36), 50% (Z=0.69), 70% (Z=1.20). For 50% mortality, ML400 values (calculated from eq. [22]) are shown for the 12 populations with growth parameters shown in Fig. 12a. In b), L_∞ has been transformed to age at 400 mm.

These results can be expressed in a form that allows a growth index (A400) to be used instead of L_∞ when evaluating mortality. Transformation of the x-axis in Fig. 14a (from eq. [20]) results in an inverse

relationship between ML400 and A400 (see Fig. 14b). The ML400 values calculated for 50% mortality are scattered more widely around the 50% line. This demonstrates that estimates of mortality obtained by this technique will not be very precise, but they are not expected to be biased. The method could be used therefore to assess a large number of lakes and estimate the proportion of lakes in which mortality exceeds a 50% guideline. **A400 and ML400 estimates for each lake could be plotted on a graph (Fig. 14b) so that the number of points above and below the 50% line could be counted. The proportion of lakes with high mortality could then be calculated.**

SAMPLING FAU LAKES

SAMPLING FRAMEWORK AND OBJECTIVES

The FAU core data program (OMNR 1990) stipulates that harvest, effort, abundance, mortality, growth and condition should be monitored on all FAU lakes. Specifically, it states that these variables should be monitored annually for an initial 5-year period, and then for two consecutive years in each succeeding 5-year cycle. Earlier sections of this paper discussed problems in measuring these variables and proposed some measurement standards. In this section, we describe a typical year of sampling for an FAU lake that obtains the data needed to meet these standards. Sampling objectives, methods and sample size requirements are discussed.

A sampling framework suitable for the assessment of FAU lakes is shown in Fig. 15. It identifies two types of sampling procedures (EH - effort and harvest sampling; CS - catch sampling) and specifies the seasons in which they must be done. Each sampling procedure is described in separate sections below, following a discussion of sampling objectives and precision targets. Objectives are summarized in Tables 2 and 3, which list the statistics to be obtained from each sampling procedure.

Effort and harvest (EH) sampling requires a creel survey in each season that angling occurs. In most cases, this includes only the first 3 seasons of the year because lake trout fishing is closed on most lakes

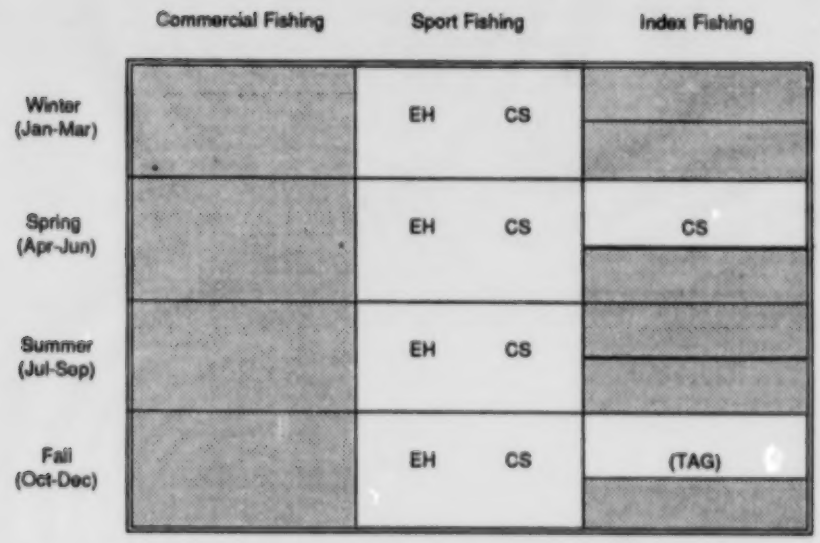


FIG. 15. Sampling framework for lake trout assessment on FAU lakes, identifying the types of sampling required in each season of a year: EH - Effort and harvest sampling, CS - Catch sampling, TAG - apply/recapture tags (during lake trout spawning).

during the fall (October-December). Access or roving creel survey methods could be used and both techniques are described below. Estimates obtained from these surveys (see Table 2) must be reported by season. Data from the FAU network could then be used to evaluate seasonal differences in lake trout catchability and estimate weighting factors needed to calculate annual effective effort (see eq. [4]). For now, it is necessary to assume equal catchability when calculating effective effort (i.e. B = 1 for each season). Seasonal reporting is also needed to support the shortcut method proposed for estimating effort on district lakes (see p. 22). The formula that calculates effective effort from mean midday activity (MAC) requires seasonal values for the harvest proportion (P_h), proportion of effort directed at lake trout (P_e), the catchability weighting factor (B), and the midday bias factor (K_m). We proposed above that FAU data be used to supply estimates of these parameters for different regions of the province. MAC is included as a required FAU lake statistic to facilitate analyses needed to estimate the midday bias factor.

Table 2. Statistics desired from effort and harvest sampling on FAU lakes. The + symbol indicates information is required. Seasons are abbreviated as Winter (Wi), Spring (Sp), Summer (Su) and Fall (Fa).

		Sport				
Statistic	Symbol	Wi	Sp	Su	Fa	Annual
Total catch	C	+	+	+	+	
Harvest proportion	P_h	+	+	+	+	
Mean weight of harvested fish	$\bar{w}$	+	+	+	+	
Total effort	E	+	+	+	+	
Effort prop'n	P_e	+	+	+	+	
Effective effort	$f = E P_h P_e B$	+	+	+	+	+
Harvest weight	$W = C P_h \bar{w}$	+	+	+	+	+
Targeted CUE	CUE_s	+	+	+	+	
Targeted HUEW	$HUEW_s$	+	+	+	+	
Mean party size	$\bar{p}$	+	+	+	+	
Mean midday activity	MAC	+	+	+	+	

Table 3. Statistics desired from catch sampling on FAU lakes. The + symbol indicates information is required. Seasons are abbreviated as Winter (Wi), Spring (Sp), Summer (Su) and Fall (Fa).

		Sport				Index	
Statistic	Symbol	Wi	Sp	Su	Fa	Sp	Pooled
Targeted CUE	CUE_s	+	+	+	+	+	
Length composition	P_L	+	+	+	+	+	
Age composition	P_l	+	+	+	+	+	
Total mortality	A	+	+			+	+
Growth parameters	K, L_∞	+	+			+	+
Condition parameters	a, b	+	+			+	+
Mean length above 400 mm	ML400	+	+			+	+
Age at 400 mm	A400	+	+			+	+

Catch sampling (CS) provides additional data to estimate size composition, age composition, mortality, growth and condition. The data are obtained by sampling angler catch in each season and conducting an index fishing survey during the spring. Table 3 indicates that CUE, length composition and age composition should be reported for each data source. Ideally, estimates of mortality, growth and condition should also be obtained independently for each data source so that bias due to season and fishing method could be evaluated. This may not be practical given the amount of sampling that would be needed to obtain precise estimates in each case. Because precise estimates from one (or few) data sources are more valuable than imprecise estimates from all data sources, the following sampling priorties are recommended.

Winter and spring are designated as high priority seasons in which large samples should be obtained. Sampling of angler catch is more cost effective at this time of year when most lake trout fishing occurs. Furthermore, growth and condition are better assessed early in the year when somatic and reproductive growth are minimal. Estimates of mortality, growth and condition obtained from each data source (winter angling, spring angling and spring index fishing) should be reported, as well as estimates based on pooling of these data (see Table 3). These data should also be used to evaluate the effectiveness of the mortality and growth indices proposed for district lake assessment. For this reason, estimates of mean length above 400 mm (ML400) and age at 400 mm (A400) should also be reported.

PRECISION TARGETS

One objective of this section is to specify how much sampling is needed when estimating the variables listed in Tables 2 and 3. The answer is important because it affects the precision of the results and dictates the cost of a survey. The FAU core data program suggests a minimum standard of 20% relative precision. Because relative precision is defined as the coefficient of variation (CV) of an estimate (i.e. standard error (SE) expressed as a percent of the estimate), this implies 95% confidence limits that are approximately $\pm$ 40% of the estimates. For example, if lake trout harvest was estimated as 1000 kg, a standard error of 200 is needed to meet a 20% precision target, and the approximate 95% confidence

range would be 600 to 1400 kg. On the other hand, if estimated harvest was only 100 kg, a standard error of 20 is required and the confidence range would be 60 to 140 kg. This precision target is arbitrary, but it supplies a useful standard for evaluating the cost of the FAU program in that it dictates the number of days, fishing parties, net sets and fish that should be sampled. The approach taken is similar to that described by Quinn et al. (1983) in proposing standards for sampling commercial fisheries.

Sample size determination requires an empirical approach that uses historical data to describe the inherent variability of processes sampled. The basic theory is described in Appendix D and its application in designing ecological studies is discussed by Elliot (1971), Cuff and Coleman (1979), Downing (1979), Green (1979) and Krebs (1989). Lester et al. (in press) used historical data from a large sample of Ontario lakes to develop sample size guidelines for roving creel surveys. Their results are used to supply guidelines for effort and harvest surveys. Specifically, we show how a creel survey could be planned to estimate effort at 20%, CUE at 15% and harvest weight at 25% precision. Different precision targets apply because, as we later show, it is not possible to estimate all variables at the same level of precision.

We have not determined how much sampling is needed to estimate mortality, growth and condition at a desired level of precision. To provide a guideline, we suggest that sample size requirements be dictated by the following targets:

- CV = 15% for lake trout CUE, and
- CV = 15% for the estimated proportion of fish in the most abundant age group (P_1).

The first target dictates how many interviews (for angling) and net sets (for index fishing) are needed to estimate CUE. The second indicates how many fish must be sampled. The precision of mortality, which is estimated from age specific CUE, is affected by both sample sizes, but growth and condition are affected only by the number of fish sampled. In the "catch sampling" section, we show how the sample size for number of fish can be determined and provide a rough estimate of its size. We also develop a formula for calculating how many net sets are needed by an index fishing survey to estimate CUE (mean catch) at 15%

precision. The comparable requirement for estimating angling CUE (i.e. number of interviews) is discussed within the "effort and harvest sampling" section where the same precision target applies.

EFFORT AND HARVEST SAMPLING

Methods of sampling angling effort and harvest are dictated mainly by access to the water body. If access is restricted to one or few sites, access point sampling is efficient. The survey contacts anglers as they leave the water body and obtains necessary data by counting parties, interviewing some or all parties, and sampling their harvests. When several access points exist, they can be identified as different spatial strata, so that only one access point need be covered on a given day.

Roving survey methods (Neuhold and Lu 1957; Robson 1960, 1961; Grosslein 1962; Regier 1966; Olver 1970; Malvestuto et al. 1978; Malvestuto 1983) have been developed because access point methods are not efficient when many access points exist. The technique does not require a count of the total number of parties fishing on a given day, nor does it require that parties be interviewed when they have completed fishing. "Instantaneous" counts of the number of parties (or anglers) fishing are taken at randomly selected times within the fishing day by cruising the lake or using aerial survey methods. Parties are randomly interviewed, usually while they are fishing. They can also be interviewed at access points, providing that a representative sample of parties can be obtained in this manner.

Stratified two-stage sampling designs apply in most roving and access surveys. Spatial stratification is usually defined for practical reasons: to sample several access points in access surveys or to identify areas small enough to obtain "instantaneous" counts in roving surveys. Other forms of stratification (e.g. day types, date ranges) are often used to obtain greater precision, when effort or CUE vary over time. Within-day stratification is useful in roving surveys, when it successfully divides a day into high and low fishing activity periods. In access surveys, it is useful when it divides the day into periods which differ in terms of the number of fishing trips completed within each period.

Two-stage sampling applies because sample units are selected first by random selection of days, and then, by random selection of units within days. These (second-stage) units include parties that are interviewed and harvested fish that are weighed. In roving surveys, points in time (when activity counts are made) represent an additional sample unit.

Most surveys of Ontario lakes have used roving survey methods. For this type of survey, we describe estimation methods and provide sample size guidelines. For access surveys, estimation methods are described, but samples size requirements are not discussed. Sufficent historical data were not available to develop such guidelines.

Roving Surveys

Methods of estimating effort and harvest from stratified two-stage roving survey designs are described by Lester & Trippel (1985) and Orsatti et al. (in press). First, estimates of effort and harvest are calculated for each sample day (Table 4). Then, mean daily estimates are calculated for each stratum and the variation among daily estimates is used to calculate the variance of each mean estimate. (Effort calculations are shown in Table 5, but similar formulae apply for harvest estimation.) These means are expanded by the number of days in the stratum to calculate stratum totals which are then summed to calculate survey totals. Similar formulae apply in calculating the variance of stratum and survey totals (Table 5).

The standard error (and thus precision) of these estimates depends on the number of sample days and how much sampling is done within days. As within day sample sizes (i.e. number of counts, interviews and fish) increase, daily estimates become more precise and relatively fewer days are needed to obtain the same precision for survey estimates. Determining the sample sizes required to achieve precision targets for effort and harvest is difficult, however, because these variables are calculated as products of variables whose precision depends on different types of sampling.

Table 4. Estimation of effort and harvest for each sample day (i) in roving and access creel surveys. Symbols refer to mean no. of parties fishing per count ($\bar{A}_i$), mean no. of anglers per interview ($\bar{p}_i$), fishing day length (T), no. of parties that passed the access point (M_i), mean effort in ang-hrs per interview ($\bar{e}_i$), proportion of observed effort targeted on lake trout ($P_{e,i}$), proportion of observed catch harvested ($P_{h,i}$), mean weight of fish sampled from the harvest ($\bar{w}_i$), mean no. caught per interview ($\bar{c}_i$), mean no. harvested per interview ($\bar{h}_i$).

Estimate for day i	Formula
Effort (roving)	$E_i = \bar{A}_i \bar{p}_i T$
Effort (access)	$E_i = M_i \bar{e}_i$
Lake trout effort	$E_{s,i} = E_i P_{e,i}$
Harvest weight (W)	$W_i = E_i \, CUE_i \, P_{h,i} \, \bar{w}$
	where $CUE_i = \frac{\bar{c}_i}{\bar{e}_i}$; $P_{h,i} = \frac{\bar{h}_i}{\bar{c}_i}$

Such problems were addressed by Lester et al. (in press). They argued that the effects of different types of sample sizes could be determined by examining their independent effects on component variables. They showed that the precision of mean daily effort is approximated as

$$CV(\bar{E}) = \sqrt{CV^2(\bar{A}) + CV^2(\bar{p})} \qquad [24]$$

where component variables are survey estimates of mean activity ($\bar{A}$) and mean party size ($\bar{p}$). Similarly, the approximate precision of mean daily harvest weight ($\bar{W}$) is

$$CV(\bar{W}) = \sqrt{CV^2(\bar{E}) + CV^2(CUE) + CV^2(\bar{P}_h) + CV^2(\bar{w})} \qquad [25]$$

where component variables are mean daily estimates of effort ($\hat{E}$), catch-per-unit-effort (CUE), the proportion of the catch harvested (P_h) and the mean weight of harvested fish ($\bar{w}$).

Table 5. Formulae for estimating effort for each stratum (h) and the entire survey. Symbols refer to effort for day i in stratum h (E_{hi}), no. of days sampled in stratum h (n_h), no. of fishing days in stratum h (N_h), the total number of strata (H). Variance formulae ignore finite population correction factors which should be applied in access surveys.

Estimate	Formula
Mean (daily) effort for stratum h	$\bar{E}_h = \frac{\sum_{i=1}^{n_h} E_{hi}}{n_h}$
Variance of estimated mean effort for stratum h	$var(\bar{E}_h) = \frac{s_h^2}{n_h}$ where $s_h^2 = \sum_{i=1}^{n_h} \frac{(E_{hi} - \bar{E}_h)^2}{n_h - 1}$
Total effort for stratum h	$E_h = N_h \bar{E}_h$
Variance of total effort for stratum h	$var(E_h) = N_h^2 \, var(\bar{E}_h)$
Total effort for survey	$E = \sum_{h=1}^{H} E_h$
Variance of total effort for survey	$var(E) = \sum_{h=1}^{H} var(E_h)$
Standard error of total effort for survey	$se(E) = \sqrt{var(E)}$

Lester et al. (in press) developed formulae for calculating the sample sizes needed to estimate mean activity (Å), CUE and mean party size (β) at desired levels of precision. Their results indicate that the number of parties needed to obtain a precise estimate of mean party size is very small relative to the number required to estimate CUE. CV(β) will be negligible when CUE is estimated at reasonably high levels of precision, and, thus, the precision of effort is dictated largely by the precision of mean activity.

Guidelines for estimating effort can be supplied therefore by a sample size formula for estimating mean activity (from Lester et al. in press):

$$n = \frac{1}{CV^2}\left(\frac{1}{A} + \frac{1}{3.2}\right)\left(0.5 + \frac{1}{m}\right) \qquad [26]$$

where n is the number of sample days, m is the number of activity counts per day and CV is the desired precision expressed as a proportion. The equation implies that the required number of sample days (n) decreases as mean activity increases and as more counts per day (m) are made. This is illustrated in Fig. 16a which describes requirements for estimating mean activity at 20% precision (CV = 0.20).

Guidelines for estimating CUE are given by the formula

$$n = \frac{1}{CV^2}\left(\frac{0.87}{CUE^{0.75}}\right)\left(0.10 + \frac{1}{m}\right) \qquad [27]$$

where n is the number of days sampled, m is the number of interviews per day and CV is the desired precision. Fig. 16b describes sampling needed to estimate CUE at 15% precision. It demonstrates that the number of sample days decreases as CUE increases and as more interviews per day are made. An alternative way of viewing CUE sampling requirements is to specify the total number of interviews required (Fig. 17).

The precision of harvest weight depends on the precision of effort, CUE, harvest proportion (P_h) and mean weight ($\bar{w}$). It follows (from equation [25]) that harvest weight cannot be estimated more precisely than effort. Given 20% precision for effort and 15% precision for CUE, the best precision that could be obtained for harvest weight is 25%. This assumes negligible values for CVs of P_h and $\bar{w}$ (mean weight). For P_h, the assumption is reasonable because the harvest proportion is expected to be high (i.e. > 0.80) and could therfore be estimated precisely from a small sample (i.e. number of interviews). Less precise estimates

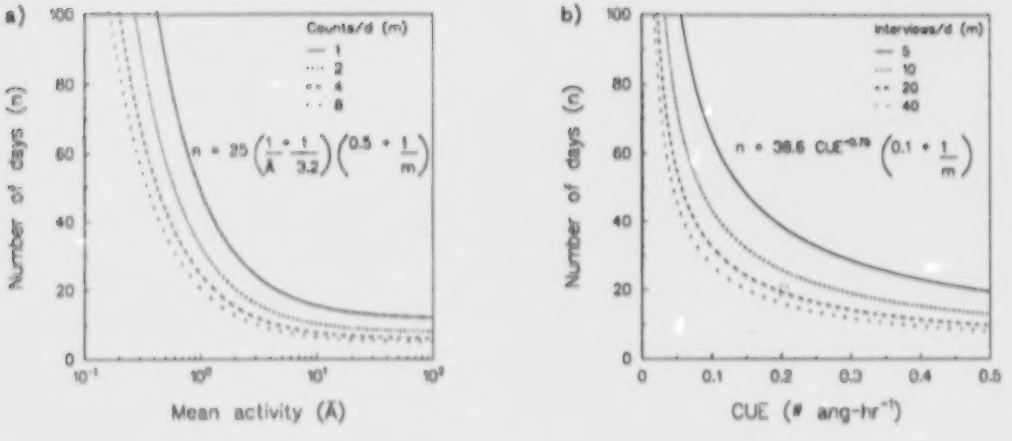


FIG. 16. Sample sizes for estimating (a) mean activity at 20% precision and (b) angling CUE at 15% precision. In a), the number of sample days (n) is plotted against mean activity for several values of m, the number of counts per day. In b), number of sample days (n) is plotted against CUE for several values of m, the number of parties interviewed per day. Formulae given in each graph were obtained from equations [26] and [27] by setting CV = 0.20 in (a) and 0.15 in (b).

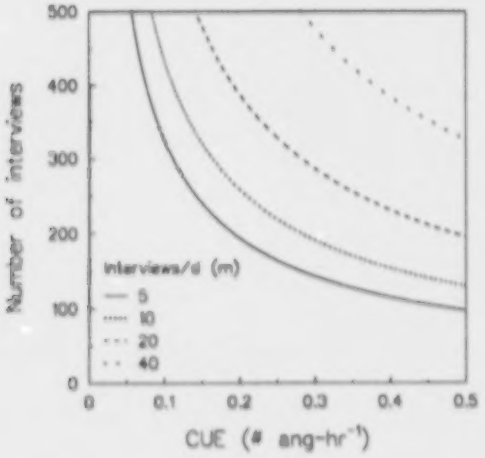


FIG. 17. The total number of interviews needed to estimate angling CUE at 15% precision. This is calculated (from requirements shown in Fig. 16b) as the number of days times the number of interviews per day.

are expected for mean weight ($\bar{w}$). A cursory analysis (based on two lakes) indicates that at least 100 fish are needed to estimate mean weight at 5% precision. The resulting precision of harvest weight (calculated from equation [25]) would therefore be approximately 27% (CV = 0.27).

When planning a survey, expected values for mean activity and CUE must be supplied. For example, if prior information suggested a mean activity of 10 parties and CUE of 0.20, reading from graphs in Fig. 16 indicates:

- effort estimation requires between 10 and 20 d, depending on the number of counts per day;
- CUE estimation requires between 15 and 40 d, depending on the number of parties interviewed per day.

Sampling of only 15 d would be sufficient if at least 2 activity counts were made each day and 40 parties were interviewed each day. Alternatively, one might sample 20 d, taking a single activity count per day and interviewing only 20 parties per day. The example demonstrates that several strategies are expected to give the same results in terms of the precision of survey estimates. The best strategy is the one that can be implemented at lowest cost.

These sample size formulae were developed from season and day type stratified data. The activity sampling guidelines describe, therefore, the sampling needed to estimate mean activity (and thus effort) at 20% precision within a given season and day type. If mean activity does not differ among strata, the sample sizes given in Fig. 16a indicate the total number of days to sample. If season or day type differences exist, the stratified mean ($\bar{A}$) should be used (in equation [26]) to determine the total sampling requirement. This mean is calculated as

$$\bar{A} = \frac{\sum_{h=1}^{H} N_h \bar{A}_h}{\sum_{h=1}^{H} N_h} \qquad [28]$$

where subscript h refers to a stratum, H is the number of strata, N_h is stratum size (i.e. number of days) and $\bar{A}_h$ is mean activity in each stratum. Sample days should be allocated optimally among strata. That is, the number of days sampled in each stratum should be proportional to stratum size times the standard deviation of mean activity (Cochran 1977). Given that standard deviation increases in proportion to mean activity (Lester et al. in press), expected means for each season and day type stratum can be substituted for standard deviations when planning an optimal allocation of sampling effort. The number of sample days for each stratum (n_h) can be calculated as

$$n_h = \frac{N_h \bar{A}_h}{\sum_{h=1}^{H} N_h \bar{A}_h} n \qquad [29]$$

where n is the total sampling requirement indicated by the stratified mean (equation [26]).

If spatial stratification applies, a maximum estimate of total sample size should be calculated from the average of expected means in each spatial stratum. This spatially stratified mean should be substituted for $\bar{A}$ in equation [26]. The value obtained for n is interpreted as the sum of days sampled in each stratum. This is a maximum estimate of sampling requirements, because they depend on the number of strata, variation in activity among strata and how sample days are allocated across strata. When activity levels are the same in each stratum, this is a correct estimate of sampling needed to obtain 20% precision.

Access Surveys

Methods of estimating daily effort and harvest from access survey data are shown in Tables 4 and 5. Formulae are the same as for roving surveys except that daily effort (Table 4) is calculated as mean effort per interview multiplied by the number of parties that passed the access point. Because access surveys obtain complete trip data and count the number of parties that fished on a given day, precise estimates of daily effort and harvest can result. In fact, if all parties are interviewed, daily estimates are measured

without sampling error. The number of sample days required in access surveys will be less than the requirement for roving surveys because the latter method does not obtain precise daily estimates and must therefore compensate by sampling a larger number of days.

The paucity of access survey data from Ontario lakes suggests many biologists may not have appreciated that access surveys are usually more efficient than roving surveys. They should always be implemented if the number of access points is small. On small lakes where a large portion of the lake can be viewed from one location, they can also be implemented when access is unlimited. Anglers can be watched and asked to report when they have completed their fishing so that data are obtained as if access point sampling were done. This technique has been successfully employed by the Algoma FAU to reduce survey costs.

CATCH SAMPLING

Angling Data

Angler catch sampling obtains catch and effort data (for a random sample of parties) and length, weight and age data (for a random sample of fish). The catch, not the harvest, is identified as the target population for sampling fish. This eliminates bias due to angler preference in the sizes of fish kept; bias that remains is due to gear selectivity. Although details about released fish are hard to obtain, approximate size data could be supplied by anglers and should be recorded so that bias can be evaluated. Otoliths are needed to determine age in older fish and should be obtained (in addition to scales) if anglers give their consent.

Mortality should be estimated by comparing the abundance of each cohort to its abundance in the previous year of sampling (see p. 32). Age specific indices of abundance should be calculated as

$$CUE_{s,t} = CUE_s P_t \quad [30]$$

where $CUE_{s,t}$ is targeted CUE for age t fish, CUE_s is targeted CUE overall and P_t is the estimated proportion of fish of age t.

The length and age composition should be reported by calculating the proportion of fish in various length and age groups. For length composition, we recommend fork length intervals of 40 mm. Growth and condition parameters should be estimated using the regression methods, based on individual fish, described above (see p. 33).

The sample size for number of fish should be based on a 15% precision target for estimating the proportion of fish in the most abundant age group. A minimum estimate can be obtained as follows. The formula for variance of an estimated proportion (Cochran 1977) implies a coefficient of variation which is expressed as

$$CV(P_t) = \sqrt{\frac{(1-P_t)}{nP_t}} \quad [31]$$

where n is the number of fish sampled. Setting CV = 0.15 and solving for n gives

$$n = 44.4 \frac{(1-P_t)}{P_t} . \quad [32]$$

The sample size depends on P_t, the proportion of the catch that is represented by the most abundant age group. Results from previous surveys of a lake should be consulted to determine an expected value for this variable. Assuming $P_t = 0.30$ (i.e. 30% of the catch is of one age), this formula indicates 104 fish should be sampled.

A catch sample of 100 fish is proposed as a minimum target. For most lake trout populations, many age groups will be represented in the catch, and the most abundant group will often be less than 30%. A larger sample size is needed when this is the case. Because young fish are most abundant, this level of sampling does not provide very precise estimates of the proportion of fish in older age groups. For example, the coefficient of variation of P_t for age groups whose proportions are 0.10 and 0.05 will be 30% and 44%, respectively. A larger sample size is desirable and may be particularly important for estimating growth. Because variation in length is greater for older fish, relatively larger numbers of old fish are desired for estimating growth. This requires a fairly large sample size because older fish are less abundant.

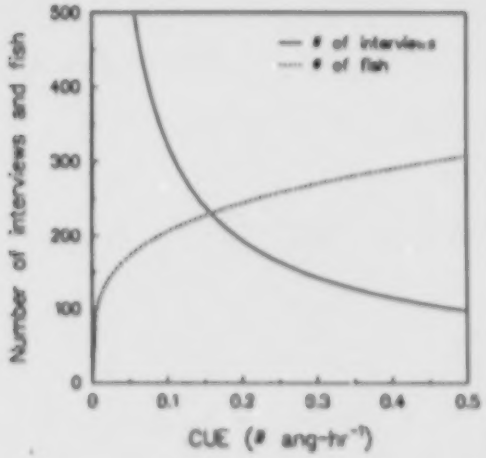


FIG. 18. The number of fish captured by parties interviewed in a creel survey, given that sampling was designed to estimate CUE at 15% precision. The sample size for interviews assumes 5 interviews per day (i.e. m = 5 in Fig. 17). The expected observed catch was calculated as: (# of interviews) x (6.3 ang-hr/interview) x CUE. Angling effort per interview was estimated from historical roving survey data.

Sample sizes greater than 100 fish should be available in most angler catch surveys that are designed for estimating CUE at 15% precision (Fig. 18). The graph shows the number of parties that would be interviewed and the number of fish that would be observed by the survey crew (i.e. caught by interviewed parties). Calculations used the total number of interviews guideline for five interviews per day (Fig. 17) and

assumed a mean angler-effort per party of 6.3 hr. (The latter figure was estimated from Ontario roving survey data.) The number of fish observed by the survey crew generally exceeds 100, falling below this threshold only when CUE is very low. Sampling requirements for estimating CUE and other population variables are therefore compatible. These requirements will be difficult to meet on lakes where effort is low, because a sufficient number of parties and fish may not be available for sampling.

Index Fishing Data

The index fishing procedure described in Appendix A uses 30-min sets of small mesh gill nets to sample the littoral zone during the spring. It reports the number of fish captured by each set and samples the catch for length, weight and age data. Because effort is held constant, CUE is measured as mean catch per set. Results from FAU surveys that employed this method are presented below in developing a formula for calculating how many sets are needed to estimate mean catch at 15% precision.

Results shown in Fig. 19 indicate that the mean catch of lake trout ranged from 0.17 to 4.95 per set. The relationship between variance (s^2) of the catch and mean catch ($\bar{C}$) is described by the formula

$$s^2 = 1.79\ \bar{C}^{1.39} \qquad [33]$$

Results for gillnet sampling of other species (from Moyle 1950) are also shown in Fig. 19. They demonstrate that a similar relationship exists, in spite of the fact that different species and netting methods apply.

Equation [33] can be used to determine how many sets (n) are needed to estimate mean catch at a required level of precision (Appendix D). The general formula implied is

$$n = \frac{1.79}{\bar{C}^{.61}\,CV^2} \qquad [34]$$

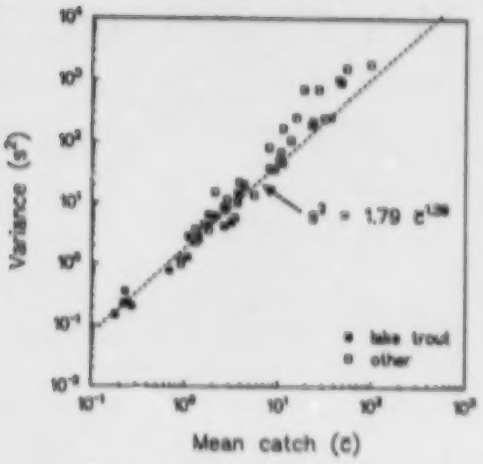


FIG. 19. The variance-mean relationship for number of fish captured in index fishing surveys. Results from seven surveys that employed the gillnet sampling methods described in Appendix A are shown as filled squares. Mean catch ($\bar{c}$) and variance (s^2) were calculated for each mesh size. Regression of log transformed values gave $\log_{10}s^2 = 0.253 + 1.39 \log_{10}\bar{c}$, implying the power function relation indicated by the dotted line in the graph. Open squares are results from Minnesota gillnet surveys (data from Moyle 1950) and refer to various species (northern pike, walleye, yellow perch).

Sample sizes needed for 15% precision (CV = 0.15) are demonstrated in Fig. 20. The required number of sets decreases as mean catch increases. Sample sizes that were used in various surveys are also indicated in Fig. 20, plotted against mean catch. These points indicate that required sample sizes are obtainable. Although 15% precision is fairly costly when lake trout abundance is low (i.e. 200 sets were needed for two lakes), the few data available suggest sample sizes as small as 40 sets are needed when abundance is high.

Sampling to meet a 15% precision target for estimating mean catch will result in a variable number of fish samples. The dotted line in Fig. 20 indicates the number of fish that would be captured if the number of sets was determined by this guideline. The number of fish ranges from approximately 50 to 125 for the observed range in mean catch. It was previously shown, when discussing angler catch sampling, that at least 100 fish would be needed to meet a precision target specified for estimating the proportion of fish in

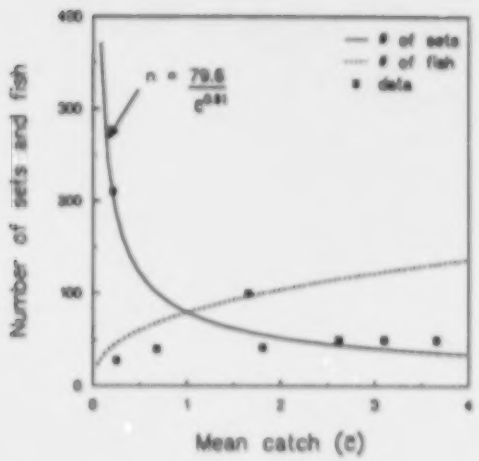


FIG. 20. The number of gillnet sets required to estimate mean catch at 15% precision, shown as a function of mean catch. Points show the mean catch and number of sets employed in the seven surveys whose data were used to determine these sampling requirements. The formula for number of sets was obtained from eq. [34] by setting CV = 0.15. The expected total catch (i.e. number of fish available for sampling) is also shown.

the most abundant age group. This sample size will not be achieved when mean catch is less than two fish per set. Although the precision standard for mean catch estimation could be altered so that more sets are required (and thus more fish are captured), this is not recommended, given the increase in costs that would result. It is simply acknowledged that precision targets related to the number of fish sampled will be difficult to achieve when lake trout abundance is low.

SAMPLING DISTRICT LAKES

SAMPLING FRAMEWORK AND OBJECTIVES

The objective of the district lake program described here is to describe the status of lake trout in a geographical region such as an entire district or a portion of a district. A sample of lakes should be assessed to determine how effort, abundance, mortality, growth and condition deviate from reference values proposed for these variables. Methods described for sampling FAU lakes are not appropriate because they are too expensive and could not be widely applied given a limited budget for the assessment of district lakes. An alternative approach that uses relatively small sample sizes and indirect assessment methods developed in this paper will be described.

The program distinguishes three types of assessment that may apply to any district lake: resource inventory, effort indexing and catch indexing. Resource inventory uses standard methods documented in the OMNR Manual of Instructions for Aquatic Habitat Inventory Surveys (OMNR 1987). These surveys are used to:

- describe lakes in terms of morphological, physical, chemical, and fish community type characteristics;
- identify potential stressors using rudimentary measures such as pH, hypolimnetic oxygen, secchi depth, etc.; and
- estimate resource potential (i.e. potential harvest).

This information should be used to set priorities for further study. In general, geographical areas containing high valued and potentially stressed lakes will be selected for additional study.

Effort indexing is done in each season (see Fig. 21) to estimate mean midday activity (MAC), an index of fishing effort. Annual effective effort is calculated from these indices (eq. [4] and [10]) and this value is compared to a reference value that depends on lake area (Fig. 3), so that the lake can be classified as being high or low effort.

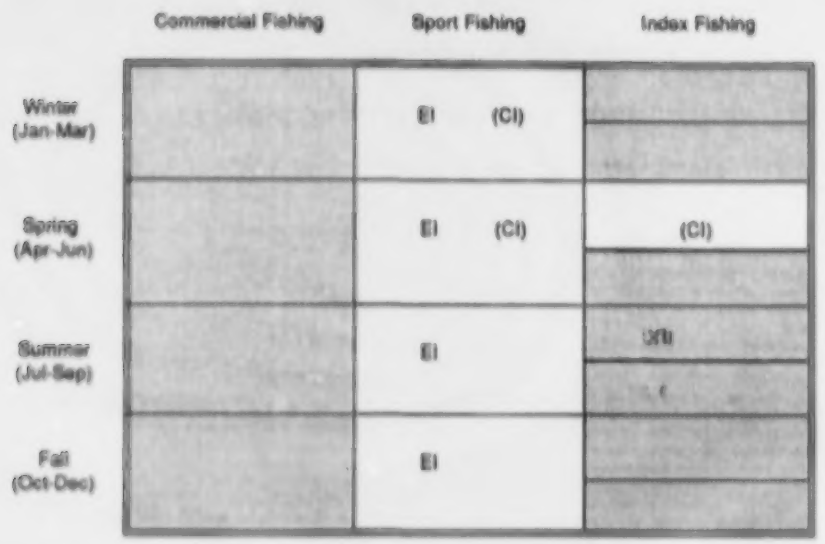


FIG. 21. Sampling framework for lake trout assessment on district lakes, identifying the types of sampling required in each season of a year: EI - Effort indexing. CI - Catch indexing. CI is shown in brackets to signify that only one of the three strata labelled CI need be sampled.

Catch indexing uses angling or index fishing data to evaluate abundance, mortality, growth and condition of lake trout. Because compatibility with FAU data is needed, the sampling framework (Fig. 21) specifies that catch indices can be obtained from winter or spring angling data or from spring index fishing data. Angling data are expected to be more cost effective on high effort lakes where relatively large numbers of anglers could be contacted easily. On low effort lakes it is more difficult to obtain angling data and index fishing may offer a cheaper source of data. **The statistics required include indices of abundance (CUE, HUEW), growth (A400) and mortality (ML400), and estimates of weight-length parameters (a,b). They should be compared to reference values given above so that lakes can be classified as high or low with respect to each variable.**

Fig. 22 illustrates how this type of program could be implemented on a 5 yr planning cycle. Minden District was chosen as a example district. Resource inventory has been done for approximately 600 of 1322 lakes

in the district. From resource inventory results, the district considers approximately 300 lakes as "significant" (W. Wilson, OMNR, Minden, Ont. K0M 2K0, pers. comm.). Only 80 of these lakes contain lake lake trout, and, for illustrative purposes, these are represented in Fig. 22 as 16 lakes in each of five areas. Within each area, a random sample of 10 lakes (for example) is chosen and these are sampled using effort and catch indexing methods. Sampling costs are distributed evenly over years because a different area is sampled each year. Given an annual budget that allows effort and catch indexing on 10 lakes, a total of 50 lakes (i.e. 75% of the district's lake trout lakes) would be evaluated over the 5 yr cycle. The cost per lake depends on how much sampling is considered necessary for estimating effort and catch indices. The sample sizes suggested below are relatively small. They will not yield precise estimates for individual lakes, but allow a larger number of lakes to be assessed.

	Area 1 (16 lakes)	Area 2 (16 lakes)	Area 3 (16 lakes)	Area 4 (16 lakes)	Area 5 (16 lakes)
Year 1	EI: 10 CI: 10				
Year 2		EI: 10 CI: 10			
Year 3			EI: 10 CI: 10		
Year 4				EI: 10 CI: 10	
Year 5					EI: 10 CI: 10

FIG. 22. Demonstration of how the district program could be implemented on a 5 year planning cycle. Symbols defined in Fig. 21.

EFFORT INDEXING

Aerial survey methods that sample midday activity on several lakes per flight are recommended for effort assessment because they are expected to be more cost effective than ground surveys. Sampling must be done in each season that angling occurs so that seasonal estimates of effort can be obtained. Within a time window of 1000 to 1400 hrs, random sampling techniques should apply: sample days and sample times should be selected randomly to ensure that midday counts are comparable among surveys. On each sample day, a single count of fishing parties should be taken on each lake.

A total sample size of 40 days is recommended. This sample size can result in fairly precise estimates of mean midday activity if sampling effort is allocated optimally among seasons and day types. Knowledge of season and day type differences in fishing activity should be used therefore when planning the survey. The optimal design, which minimizes variance given a fixed sample size, requires that sample sizes for each stratum are proportional to the product of stratum size (i.e. number of days) times the standard deviation of mean activity (Cochran 1977). More variable strata should receive proportionately more sampling.

An approximate method that simplifies calculation of optimal sample sizes is available using mean activity values to substitute for standard deviations. Expected values of mean activity (or daily effort) for each season and daytype stratum should be multiplied by the number of days in each stratum. The resulting products indicate the relative amount of sampling that should be allocated to each stratum. This technique is expected to result in an approximate optimal allocation because the standard deviation of fishing activity increases roughly in proportion to the mean (see Lester et al. in press).

Results should report estimates of mean midday activity for each season and effective effort for the entire year. Mean midday activity (MAC) should be calculated in each season as the stratified mean of estimates for each day type.

$$MAC = p_1 \bar{A}_1 + p_2 \bar{A}_2 \quad [36]$$

where $\bar{A}_1$ and $\bar{A}_2$ are activity means for different day types and p_1 and p_2 are the proportions of weekdays and weekend days. **Annual effective effort should be calculated from equations [10] and [4], using parameter values listed in Table 1.** The result should be interpreted as a maximum estimate of lake trout effort because values of P_e (in Table 1) assume all effort is directed at lake trout. **This result should be compared to a reference value, which depends on lake area (Fig. 3), so that the lake can be classified as high or low effort.**

CATCH INDEXING

Angling Data

On-site interviewing is the preferred method of contacting anglers. Passive (i.e. angler diary) methods can be used, but they are less likely to provide necessary fish data (especially age). Also, they tend to give higher estimates of CUE (Sztramko et al. in press), presumably because experienced anglers are more likely to report their results. Diary methods are best used to supplement data obtained from interviews, in which case bias can be measured and accomodated when interpreting results. A particularly valuable contribution of diary data is information about harvest selectivity (i.e. angler preference for keeping certain sizes of fish). This property cannot be assessed from interview data because released fish are not available at the time of interview; only harvested fish are sampled.

Active sampling methods should exploit shortcuts that increase angler contact rates and are not expected to bias the results. Sampling only on weekend days (distributed across the season) is recommended, because historical data indicate that weekend daily effort is at least twice as high as weekday effort during winter and spring seasons. Sampling at lake or road access points is better than roving (i.e. lake cruising) methods. The amount of effort and number of fish sampled per interview is greater than for roving methods, because access point sampling obtains complete trip data. Consequently, fewer interviews are needed to obtain the same level of precision for various estimates. It is not necessary to sample all access

points or to monitor selected points for the entire fishing day. Access points at which activity is relatively high should be sampled at the time of day when anglers are expected to complete their trips. If roving survey methods are used, cruises should be conducted when most contacts are expected to be made.

A recommended sampling target is 40 parties seeking lake trout. Sampling should be done on at least 5 days, widely representative of the season. All fish should be sampled because the number of fish encountered when interviewing only 40 parties is relatively small. We estimate that this number ranges from approximately 32 to 64 fish as CUE increases from 0.1 to 0.2 fish ang-hr^{-1}. These calculations assume completed trip sampling, a mean trip duration of 4 hr and a mean party size of 2 anglers, giving 320 (= 40 parties x 4 hr x 2 anglers/party) as an estimate of the number of ang-hr interviewed.

Data requirements are summarized as follows. Fishing effort, catch and harvest should be recorded for each interview. Fork length and weight should be measured and scale samples collected for all fish. Otoliths should also be obtained from larger fish (e.g. > 400 mm) if anglers give their consent. Although the methods proposed for evaluating growth and mortality require age data only for fish ranging from 300 - 500 mm FL, ageing structures should be collected (but not analyzed) from other fish. This ensures that the data are available if changes in assessment methods are called for in the future.

The following statistics should be reported for each lake: CUE_a, $HUEW_a$, ML400, A400 and weight-length parameters (a and b). Calculation methods, described in previous sections of this report, are summarized in Table 6.

Index Fishing Data

Index fishing surveys must employ the standard gillnetting method described in Appendix A. A minimum sample size of 36 net sets is recommended. Because the set duration is only 30-min and 12 sets could be made on each sample day, only 3 days of sampling would be needed. These sample days should

Table 6. Summary of methods for calculating catch indices.

Statistic	Data	Calculation method
Angling abundance indices (CUE_a, $HUEW_a$)	For m parties seeking lake trout: e_j angler effort (ang-hr) c_j # caught	$CUE_a = \frac{\sum_{j=1}^{m} c_j}{\sum_{j=1}^{m} e_j}$
	For n harvested fish samples: w_j fish weight (kg)	$HUEW_a = CUE_a \frac{\sum_{j=1}^{n} w_j}{n}$
Index fishing abundance index (CUE)	For n gillnet sets: c_j # caught	$CUE = \frac{\sum_{j=1}^{n} c_j}{n}$
Mortality index: mean length above 400 mm (ML400)	For n fish > 400 mm: L_j fork length	$ML400 = \frac{\sum_{j=1}^{n} L_j}{n}$
Growth index: age at 400 mm (A400)	For fish 300-500 mm FL: L_j fork length t_j age	Fit data to equation: $t = x - y \log_e(1 - zL)$ Use x, y and z to calculate: $A400 = x - y \log_e(1 - z\,400)$
Condition parameters (a,b)	For all sampled fish: L_j fork length w_j weight	Fit data to equation: $\log_{10} w = a' + b \log_{10} L$ Use a' to calculate a: $a = 10^{a'}$

be randomly selected from available days (i.e. after ice melt and before surface water temperature reaches 13° C). The number of lake trout captured by each set should be recorded and all fish should be sampled for length, weight and age. Treatment of the data is the same as for angling data (see Table 6), except that CUE is reported as mean catch (in number) and HUEW does not apply.

INTERPRETING RESULTS

Table 7 describes a format for reporting results from individual lakes. The table lists assessed values of annual effective effort, CUE, HUEW (angling only), mean length above 400 mm, age at 400 mm and condition parameters (a,b). Annual effective effort is calculated from equations [10] and [4], and the other assessed values are determined from the equations given in Table 6. A reference value for interpreting each variable is inuicated in Table 7. In most cases, this reference is either a constant or calculated as a function of lake area. Reference values for growth and mortality indices, however, must be determined from graphs (Fig. 11b, Fig. 14b). The reference value for the growth index (age at 400 mm) decreases with lake area because faster growth is expected in larger lakes. The reference value for the mortality index (mean length above 400 mm) depends on growth, and the growth index must be used to determine what mean length is expected when annual mortality is 50%. High mortality is indicated by a mean length which is less than the reference valut.

The results for each variable can be summarized by calculating the ratio of assessed value to reference value and assigning a status score depending on whether the assessed value was less than (-1), equal to (0) or greater than (+1) the reference value. Testing for significant differences from reference values is not considered necessary. This would often result in a large number of insignificant differences because each lake was assessed from a small sample size and statistical power would be low (Peterman and Bradford 1987; Parkinson et al. 1989; Peterman 1990). Because many lakes are assessed and the objective is to describe the overall status of lake trout, it is sufficient to specify arbitrary thresholds for claiming that the assessed value deviates from the reference value. This approach is demonstrated in Fig. 23, using effort and catch results to classify lakes into stages of fishery development.

Table 7. Reporting of district lake results.

Diagnostic variable	Assessed value (X)	Reference value (X^*)	Ratio (X/X^*)	Status (-1,0,+1)
Annual effective effort (f)	_____	$155.7\ Area^{0.54}$	_____	_____
Abundance: Angling no. (CUE_n)	_____	0.20	_____	_____
Angling wt. ($HUEW_n$)	_____	$0.036\ Area^{0.22}$	_____	_____
Index fishing (CUE)	_____	(not available)	_____	_____
Mortality (ML400)	_____	(see 50% line in Fig. 14b)	_____	_____
Growth (A400)	_____	(see Fig. 11b)	_____	_____
Condition parameters: a	_____	3.88×10^{-6}	_____	_____
b	_____	3.18	_____	_____

Fig. 23 reproduces the historical data presented originally in Fig. 5. Ratios of assessed to reference values for CUE are plotted against the corresponding ratios for annual effort. Ratios of 2 (i.e. assessed value = 2 x reference) and 0.5 (i.e. assessed value = 1/2 x reference) are specified as thresholds for claiming a deviation. These thresholds are indicated by the square box in the middle of the graph. Points which lie inside this box signify lakes where effort and abundance are close to optimal use levels (i.e. 16 of 75 lakes, 21%). Points outside the box would be used to count the number of lakes in each of four development stages (see Fig. 2b): stage I - 13 (17%), stage II - 0 (0%), stage III - 19 (25%), stage IV - 27 (36%). Although mistakes will be made in classifying individual lakes, because estimates are not very precise, these mistakes are expected to cancel each other and, thus, would not bias measurement of the proportion of lakes in each category.

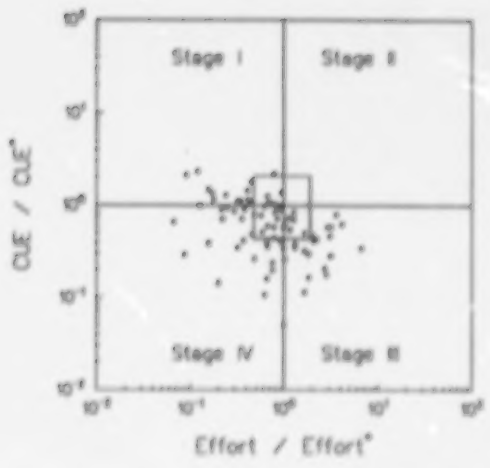


FIG. 23. Example of how CUE and effort data could be interpreted, using arbitrary thresholds for claiming that assessed values deviate from reference values. Data reproduced from Fig. 5.

This type of graph, or its summarization in terms of the distribution of development stages, supplies a useful means of comparing the status of lake trout in different geographical areas or at different times in the same area. The same technique could be applied using HUEW instead of CUE as a measure of abundance and it is expected to yield similar results. Results for other variables could be summarized independently simply by calculating the proportion of lakes in which the reference value is exceeded. Mortality results are expected to reflect effort results. On the other hand, growth and condition results are expected to corroborate abundance findings because these variables are second order responses driven mainly by shifts in abundance. Thus, if abundance was low for a large proportion of lakes, one expects a large proportion of lakes will be characterized by high growth and high condition. Similarly, a large proportion of high mortality lakes would be expected if effort was high in many lakes.

DISCUSSION

This report has defined assessment roles for FAUs and districts and called for an integrated (complementary) approach to monitor the status of lake trout in Ontario lakes. The FAU program involves detailed study of relatively few lakes. It monitors lakes on a trend-through-time basis, supplying information needed to develop models and identify conditions expected in healthy populations. Because districts are responsible for managing large numbers of lakes, they must by necessity collect less detail per lake. The proposed technique involves the collection of data to test whether variables such as effort, abundance, mortality, growth and condition deviate from values prescribed for healthy populations. The cost per lake is low relative to the FAU program because time series study is not needed, harvest is not estimated, most variables are assessed from a single season of sampling, and empirically based methods are used to evaluate some variables (i.e. effort, mortality and growth).

Historically, the synthesis of provincial fisheries information has been hampered by inconsistencies in the collection, analysis, and reporting of data. With the creation of the FAU network and the development of electronic data processing capabilities, it was expected that such problems would disappear. This synthesis has indicated, however, that the standardization needed to ensure comparable information from FAU studies has not been established. Although the FAU core data program (OMNR 1990) stipulates what variables should be monitored on FAU lakes (and how frequently), it does not address problems in measuring these variables. This paper addressed several important issues and proposed some new standards for FAU lake assessment.

The importance of a seasonal sampling framework for assessing sport fisheries is stressed. Seasonal reporting of harvest, effort and abundance indices is necessary to examine seasonal differences in catchability so that annual effort can be measured in units that better reflect its impact on the fish population. The development of surplus production models from harvest and effort data would benefit from these improved methods of measuring effort. This standard would also allow the specification of season

specific criteria for evaluating lake trout abundance from angling indices of abundance. Criteria proposed in this report for evaluating effort and abundance do not deal with this issue. They are based on historical effort estimates that assumed equal catchability among seasons.

A seasonal sampling framework is also important for estimating mortality, growth and condition of lake trout populations. Condition and growth parameters are subject to a bias resulting from gonadal development and somatic growth that occurs within a year. Mortality and growth are also subject to a bias that depends on size selective properties of gear and seasonal variation in the spatial distribution of lake trout. Special studies that employ tagging methods are needed on a sample of FAU lakes to determine the nature of these biases and supply an empirical basis for obtaining unbiased estimates of these variables. Until such information is available, it is necessary to work with potentially biased estimates. Separate reporting of estimates, obtained from sampling different seasons and fishing methods, provides an opportunity to evaluate this bias and decide whether such controls are necessary. This may not be possible on all lakes because sufficient sample sizes are hard to obtain when angling effort or lake trout abundance is low. For this reason, we have also suggested what pooling of data (among seasons and fishing methods) is acceptable for estimating these variables when sample sizes are small.

Gear selectivity problems stress the importance of standardized index fishing methods. This paper recommends that lake trout assessment be done using short duration small mesh gill nets to sample the littoral zone during the spring. The method is recommended because its effectiveness has been demonstrated by its application on several FAU lakes. It avoids killing fish, samples a wide size range and offers an affordable means of monitoring lake trout abundance at a reasonable level of precision. We do not argue that this is the most cost effective method of sampling lake trout. Other fishing methods, habitats, or seasons of sampling may offer the same information at lower cost, but the data are not available to evaluate different options. This is a research issue which could be implemented as a joint research-assessment project. The standard method we recommend could be supplemented by other types

of index fishing on a sample of FAU lakes to obtain the required data. Implementation of a standard should not be postponed until such studies have been completed. Adopting a standard method now is more important than adopting the best method at a later point in time.

The cost of the FAU program is high because precise monitoring of variables is called for. This paper supplied formulae needed to calculate sample size requirements and estimate sampling costs. On small lakes, we expect that sampling costs will often exceed the value of the fishery. These costs can be justified, however, because the data serve a purpose which extends beyond management of the lake from which data were collected. Detailed study of a sample of lakes is needed to develop models of lake trout systems and provide guidelines for management.

Cost effective assessment of a large number of district lakes is possible given that:

- FAU data are used to support an "indirect rapid methods approach";
- the FAU program supplies criteria for interpreting district lake results; and
- the same sampling framework applies on both FAU and district lakes.

Techniques proposed for evaluating effort, mortality and growth on district lakes are examples of an "indirect rapid methods approach" (Hoenig et al. 1987), in which easily obtained statistics substitute for parameters of ultimate concern. In each case, historical data were used to describe a functional relationship between the target variable (i.e. effort, mortality, growth) and an index which could be measured at relatively low cost (i.e. mean midday activity, mean length above 400 mm, age at 400 mm). These techniques should be further evaluated and improved as more FAU data become available. The MAC method of evaluating effort would supply better estimates if conversion parameters (Table 1) were specified for different regions of the province (and possibly different types of lakes). An empirical growth model, implied by data from 12 lakes, is the basis of growth and mortality indexing methods developed in

this paper. Growth parameters from many more lakes would supply a more solid foundation for these methods.

Examples of how FAU data can be used to establish criteria for evaluating district lakes are given in this paper. We used data from Payne et al. (1990) to demonstrate how effort and abundance guidelines can be obtained from surplus production models. These guidelines are based on expected values of variables when lakes are exploited at maximum sustainable harvest levels. The criteria proposed for effort and abundance are based on a small sample of lakes (n = 5) and should be reworked when more data are available. A lake area effect was demonstrated, but the small sample size precludes a more detailed analysis of factors affecting lake trout production. More precise meesures of available lake trout habitat, such as thermal habitat volume (Christie and Regier 1988, Payne et al. 1990), are expected to supply a better basis for establishing effort and abundance guidelines. Mortality, growth and condition guidelines could also be developed by determining what values are expected under maximum sustainable harvest conditions. This was not done in our paper because sufficient data were not available. However, the required data will be available from FAU lakes if the prescribed standards are adopted.

District lake assessment relies on comparative methods and demands compatibility with FAU data. Although different sampling methods are needed to reduce costs, the same sampling framework must apply. Effort assessment req.. ..s that an effort index is obtained for each season. Season specific criteria, supplied by FAU data, can then be used to convert these indices and estimate annual effort. Catch indexing obtains data from a single season of angling (winter or spring) or from spring index fishing to evaluate abundance, mortality, growth and condition. Criteria suggested in this paper were not stated for specific seasons and fishing methods, but this is needed at least for some variables. For example, criteria for evaluating abundance from angling data should be specified for winter and spring seasons because catchability may vary. The need to express other criteria at this level of detail depends on bias due to

season and fishing method. For example, a mean length criterion (used to evaluate mortality) should be specified for each data source if size selectivity varies among data sources.

The low cost methods proposed for district lake assessment will not result in precise estimates of lake trout variables. This is not considered necessary to decide whether management action is called for. Because lakes within a geographical region are part of a large system, sharing a population of anglers, they should not be treated as closed systems. To some extent, these lake systems may be self-equilibrating because shifts in angling effort are expected as a result of changes in lake trout abundance (Goddard et al. 1987). Management of lake systems, not individual lakes, is required. Management decisions should be based therefore on the status of lake trout within geographical areas, and we suggest this status can be better measured using imprecise information about many lakes than precise information about few lakes.

The district lake program is intended as a standard procedure that could be implemented in all districts. This paper has focussed on the problem of assessing lake trout, but basic concepts of the program apply to any species. Reference values of diagnostic variables and sampling frameworks (sampling season, habitat, and gear) will vary for other species, but similar methods are needed to implement a cost effective assessment program. The implementation of such a program does not infer that only low cost methods of assessment should be done on district lakes. More intensive sampling would be needed on large important lakes, where the value of the fishery justifies closer scrutiny, and also for experimental management projects where more precise information is needed to test hypotheses.

CONCLUSIONS

We conclude that two types of programs are needed to effectively monitor lake trout populations throughout the province: an intensive, FAU program and a less intensive, district program. Standardization of assessment methods is necessary so that information is comparable between these programs.

The **intensive FAU program** should estimate harvest, effort, indices of abundance, mortality, growth and condition parameters at standard levels of precision. Times series estimates for a variety of lakes are needed to develop models upon which management guidelines can be based. These guidelines supply criteria for evaluating the status of lake trout on district lakes. The FAU data also provide an opportunity for developing indirect, lower cost methods of assessing these variables on district lakes.

A **less intensive district assessment program** is necessary because the FAU program is too expensive to apply on a large number of lakes. Furthermore, precise monitoring is not required to decide whether management action is called for. Many lakes can be assessed at relatively low cost by sampling at low intensity and relying on indirect assessment methods developed from FAU data. The new approach developed in this paper offers an affordable means of describing the health of lake trout populations in different geographical areas (i.e. sets of lakes) and screening lakes to identify where problems are likely to exist.

RECOMMENDATIONS

- A standardized district lake assessment program should be implemented for lake trout lakes that ensures the comparability of FAU and district lake data. This program should:
    - be based on a seasonal sampling framework for assessment of the sport fishery (Fig. 1 and 21);
    - employ the proposed spring gillnetting method as an index fishing standard (Appendix A);
    - obtain point-in-time data for a large number of lakes;
    - minimize costs per lake by sampling at low intensity and relying on indirect assessment methods developed from FAU data; and
    - evaluate lakes in terms of effort, abundance, mortality, growth and condition by comparing results with reference values established from times series study of FAU lakes.

- Standards proposed for measuring diagnostic variables on FAU lakes should be incorporated as part of the FAU core data program. These include:
    - a seasonal framework for assessing sport and commercial fisheries (Fig. 1 and 15);
    - spring gillnetting as an index fishing standard for lake trout lakes (Appendix A);
    - seasonal reporting of statistics (Tables 2 and 3);
    - methods of estimating harvest, effort, abundance indices, mortality, growth and condition parameters; and
    - precision targets for estimates of these variables.

- Fall tagging should be done on a sample of FAU lakes. Recapture data obtained from the standard program (i.e. sport fish sampling in each season, spring index fishing) should be used to estimate catchability and size selectivity, and to test assumptions implicit in various assessment procedures.

- Periodic synthesis of FAU times series data should be done to:
    - update models of lake trout production systems;
    - update criteria (i.e. reference values) for evaluating district lakes; and
    - refine and further develop indirect assessment methods that are used on district lakes to reduce sampling costs.

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Appendix A. Index fishing standards.

FISHING GEAR

The recommended gear is a 46 m (150 ft) gillnet gang, comprised of three 15.2 m (50 ft) panels tied together at the brail loops. All three panels are of the same mesh size, either 38 mm (1.5 in), 51 mm (2 in), or 64 mm (2.5 in) stretched mesh. The panels are 2.4 m (8 ft) tall. The mesh is made from double-knotted monofilament; the filament diameter is 0.20 mm (38 and 51 mm meshes) or 0.25 mm (64 mm mesh). The nets are dyed light green (Miracle R-13L). They are hung on a 2:1 basis, implying that there is twice as much web as leadcork line and that the ratio of diagonals in the meshes is 1.73:1.

The nets are available from Biological Equipment (5605 Toronto Road, P.O. Box 46165, Station G, Vancouver, B.C., V6R 4G5) and are referred to as "monofilament research gill nets" by that company. (Mention of a manufacturer's product does not imply endorsement of that product by OMNR.) They are machine made in Finland according to specifications that were established by the British Columbia Ministry of the Environment. Additional details include:

- a braided lead line of 75 g/m (.3 lbs/fathom);
- cork lines are braided nylon and corks are 15 - 20 cm (6 - 8 in) apart; and
- nylon gables (side lines) approximately 18 kg (40 lb) test.

Each net costs approximately $75. The total cost of the gear (i.e. 3 gangs, each with 3 nets) is around $700. A survey of FAUs revealed that this is the most commonly used type of gill net within the FAU network.

SAMPLING METHODS

The survey occurs during daylight hours after ice melt and before surface temperature reaches 13°C. We recommend a minimum of 10 sample days for FAU lakes and 3 sample days for district lakes. In both cases, sample days should be randomly selected from expected available days and several randomly

selected sites should be sampled for 30 min each day. We recommend 12 sites per day and suggest the following procedure for selecting sample sites:

- partition the shoreline into 120 equal length sections;
- on each sample day, randomly select 12 sections without replacement;
- determine the optimum survey path (least distance) for visiting the 12 sections (sampled on one day) and set one gillnet gang in each section;
- set gangs of different mesh sizes in sequence (i.e. 38 mm at site 1, 51 mm at site 2, 64 mm at site 3, 38 mm at site 4, 51 mm at site 5, etc.) so that different mesh sizes are distributed throughout the lake and 4 sites are sampled by each mesh per day.

Gangs should be set perpendicular to the shoreline starting at a depth of 2.5 m and extending no deeper than 30 m. The starting location should be random within the section sampled, with the exception that river mouths, debris strewn areas (likely to damage nets) and very steep gradients (i.e. > 45 degrees) should be avoided. The net may be set at an angle less than 90 degrees (with respect to the shoreline) if this is necessary to avoid steep gradients.

The nets are left to fish for 30 min and the following data are obtained from each set:

- total number and weight of fish captured (by species);
- fork length, round weight and scale sample from each lake trout;
- otolith and sex from dead lake trout; and
- record of lake trout clips, tags and other marks.

Appendix B. The effects of party size and number of rods on angler effectiveness.

INTRODUCTION

Analyses of Ontario creel survey data were done to answer two questions:

- Does an angler using two rods capture lake trout more quickly than an angler using one rod?
- Does party size affect the rate at which anglers capture lake trout?

Measurement of effective effort is simplified if answers to both questions are no. If the number of rods does not affect capture rates, then angler-hours is the appropriate measure. If angler effectiveness is independent of party size, then variation in party size can be ignored when measuring effective effort.

Answers to such questions are more frequently assumed than tested. In Ontario, effort is often measured in rod-hours. During open-water seasons, this equates with angler-hours, but for winter fishing it exceeds angler-hours because two lines (i.e. rods) per angler are permitted on most lakes. Because effort is measured in rod-hours, it is often assumed that exploitation can be reduced by restricting winter fishing to one rod. This tactic has been implemented in several cases (Oliver 1988). Its effectiveness depends on whether an additional rod increases an angler's catch. Apparently, this detail has been ignored given that reports documenting such effects are lacking. Party size effects have also been ignored in most cases. Christie (1964) described problems that can result from this and showed that walleye catch rates, measured in terms of fish-per-angler-hour, decreased as party size increased.

Effects of party size and rods-per-angler can be measured by comparing catch rates for various combinations of these factors. Analyses reported in this appendix are based on the following model that describes in a quantitative fashion how these factors may influence catch rate. The model is developed from the catch equation (Ricker 1975)

$$C = qNf \qquad [1]$$

where C is the number of fish caught, q is catchability, N is fish abundance, and f is effective effort. Effective effort of a fishing party, which may depend on the duration of the trip (h), party size (p) and mean rods per angler (r), can be described by the general formula

$$f = h\,p^{x}\,r^{y} \qquad [2]$$

where x and y are parameters to be estimated. Substituting for f in equation [1] gives the following general form of the catch equation:

$$C = q\,N\,h\,p^{x}\,r^{y} \qquad [3]$$

and for catch per party-hour:

$$CPH = q\,N\,p^{x}\,r^{y} \qquad [4]$$

where CPH refers to C/h.

The exponents in this equation describe how catch rate is affected by party size and rods per angler. Values of 1 imply these variables exert their full effects. That is, the CPH doubles as party size doubles and as rods per angler doubles. Values of 0 imply they have no effect. Values between 0 and 1 measure a partial effect. For example, a value of 0.5 for the party size coefficient (x) implies that catch rate increases in proportion to the square root of party size.

Regression methods can be used to estimate x and y. First, logarithmic transformations are done to linearize equation [4]:

$$\log_e CPH = \log_e (q\,N) + x \log_e p + y \log_e r \qquad [5]$$

For open-water fisheries, rods per angler (r) equals one and this simplifies to:

$$\log_e CPH = \log_e (q\,N) + x \log_e p \qquad [6]$$

In logarithmic units, catch-per-party-hour is expected to increase linearly with party size and rods-per-angler and the slopes supply estimates of x and y, respectively. The y-intercept depends on lake trout abundance (N) and catchability (q).

METHODS

From the data archive maintained by the Ontario Fisheries Information System (OFIS), CREESYS datasets for 124 surveys containing lake trout data were obtained. Surveys with less than 50 interviews of parties seeking lake trout were rejected because they contained insufficient sample sizes for investigating differences in angler effectiveness. Surveys that interviewed anglers (not parties) were also rejected because party size data were not available. The remaining data included 34 winter surveys from 14 lakes and 39 open-water surveys from 16 lakes. Table 1 summarizes by lake the data that were used in the analyses described below.

For each survey, interviewed parties were classified according to party size and mean rods-per-angler. Total catch of lake trout (C), total party-hours (h) and catch-per-party-hour (CPH) were calculated for each combination of these factors. Multiple years of data for a given lake were combined by averaging the logarithm (base e) of CPH values. Log-CPH results are shown in Table 1.

RESULTS

Party size and rods-per-angler characteristics for winter and open-water fisheries are summarized in Fig. 1. Parties of size 2 were most frequent and party sizes greater than 4 were rare. In 75% of winter fishing parties, anglers used two rods. CPH and sample sizes (i.e. number of parties interviewed) for party sizes ranging from 1 to 4 anglers are shown in Table 1. For winter data, these results are shown separately for parties using one and two rods-per-angler.

Table 1. Summary of data available for analyses of party size and rods-per-angler effects. Log-CPH and # of interviews (N) are shown for party sizes 1, 2, 3 and 4 (denoted by subscripts). 'Reg flag' indicates data used in regression analyses.

Season	Lake no.	Lake name	# of prs	Reg flag	Rods per angler	Log-CPH$_1$	N$_1$	Log-CPH$_2$	N$_2$	Log-CPH$_3$	N$_3$	Log-CPH$_4$	N$_4$
Winter	10	Clear	2	*	1	-1.37	14	-1.05	12	-1.10	2	-0.16	7
				*	2	-1.81	20	-0.70	26	-0.97	12	-0.10	4
	14	Dickey	5	*	1	-1.91	47	-1.11	75	-0.92	24	-1.07	12
				*	2	-1.21	125	-1.16	163	-1.38	61	-1.12	35
	16	Drag	6	*	1	-0.73	66	-0.51	73	-0.21	25	-0.80	9
				*	2	-0.61	179	-0.31	191	-0.28	58	+0.19	16
	17	Elliot	2		1	-2.14	21	-2.49	24	-2.80	11		
					2	-2.41	95	-2.02	76	-2.17	26	-1.79	29
	19	Esown (Otter)	1		1	-2.48	3						
					2	-2.02	14	-1.77	20	-1.69	9	-1.95	3
	22	Joseph	1	*	1	-1.19	8	-0.68	12	-0.16	14	+0.18	7
				*	2	-1.62	153	-1.11	168	-0.68	92	-0.02	50
	24	Koshlong	2	*	1	-1.08	17	-3.04	17	-1.50	6	-1.07	5
				*	2	-0.86	89	-1.62	36	-1.22	20	-0.71	12
	26	Simcoe	2	*	1	-2.68	474	-2.52	632	-2.33	350	-2.45	176
				*	2	-2.64	840	-2.37	978	-2.37	103	-3.40	39
	28	Superior		*	1	-0.57	51	-0.07	161	-0.23	129	+0.16	82
				*	2	-0.96	402	-0.38	1365	-0.05	743	+0.17	367
	29	Loon	1		1	-0.59	2						
					2	-2.31	49	-2.04	34	-1.29	11		
	31	Minkeaki	1		1	-1.03	4	-1.25	11	-0.84	4		
					2	-1.79	24	-1.34	60	-0.58	9	-1.74	3
	33	Otterhart	1		1								
					2	-3.45	13	-1.68	23	-1.11	9	-1.62	5
	60	Trout	1		1	-1.35	20	-2.38	32	-2.10	12		
					2	-1.80	130	-2.08	114	-1.68	54	-1.68	17
	62	Twelve mile	5	*	1	-1.68	35	-1.67	110	-1.62	36	-1.54	15
				*	2	-1.98	245	-1.42	213	-1.30	14	-0.86	9
Spring & Summer	04	Big Porcupine	2	*	1	-3.06	62	-2.40	61	-1.80	9	-2.20	6
	14	Dickey	5	*	0	-1.09	207	-1.19	260	-0.40	65	-0.94	7
	16	Drag	5		1	-1.86	426	-1.85	280	-1.01	35		
	17	Elliot	1		1	-1.33	12	-1.10	28	-1.69	11		
	19	Flack	0	*	0	-1.08	79	-0.93	509	-0.81	299	-1.12	110
	20	Gang	2	*	1	-2.16	15	-2.07	198	-1.05	52	-0.29	17
	21	Goulais	2	*	1	-1.23	13	-0.76	65	-0.49	16	+0.57	17
	23	Kimball	3	*	1	-1.79	46	-1.22	182	-1.51	51	-1.04	8
	24	Koshlong	3	*	1	-1.85	141	-1.61	122	-1.62	21	-2.35	5
	27	Lavielle	2	*	1	-1.33	9	-1.29	114	-1.07	21	-1.39	4
	30	Magpian	2	*	1	-0.87	21	-0.72	131	-0.68	21	-0.01	5
	34	Opasings	2	*	1	-1.25	109	-1.21	510	-1.25	153	-1.89	19
	35	Sherborne	2	*	1	-1.83	37	-1.81	74	-1.09	13	-1.39	2
	37	Smoke	2		1	-2.21	29	-1.68	126	-1.66	24		
	42	Twelve Mile	2		1	-3.10	114	-2.11	64				
	43	White Partridge	1		1	-1.27	72	-1.27	29				

Some combinations of party size and rods-per-angler were not available for particular lakes. This resulted either because they were not observed or they were so rare that the total catch was zero (and CPH could not be reliably determined). These lakes were excluded from the regression analyses reported below. As

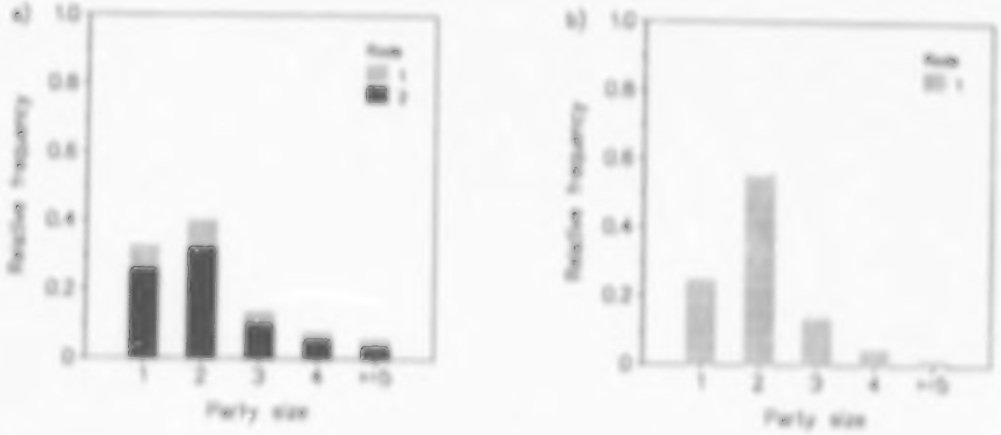

FIG. 1. Relative frequency of party sizes for winter (a) and open-water fishing (b). Results are averages of the party size distribution calculated for individual lakes. For winter fishing, frequency bars are partitioned based on the number of rods per angler.

indicated in Table 1, complete data for 4 levels of party size and 2 levels of rods-per-angler (winter only) were available from eight lakes for winter fishing and 11 lakes for open-water fishing.

To estimate the party size coefficient (α) and mean rods coefficient (γ), as defined in equation [5], analyses were done after extracting effects due to variation in lake trout abundance. Mean log-CPH for each lake was calculated by averaging across all combinations of party size and rods-per-angler. Residual log-CPH values were calculated by subtracting these means. These residuals were used in regression analyses.

Results are shown in Fig. 2. Log-CPH residuals, averaged across lakes, are plotted against the logarithm of party size. Winter results (Fig. 2a) for one and two rod anglers are indicated by different symbols. From the graph, it is clear that this factor has little effect on catch rate. Multiple regression of the winter data indicated a rods effect was not significant ($p>0.05$), but party size was ($p<0.001$). The slope of regression equation (slope = 0.43, y-intercept = -0.34, R^2 = 0.25) is less than one, implying that anglers fishing in

parties are less efficient than solitary anglers. (The dashed line in Fig. 2 shows the relationship expected if angler efficiency was not affected by party size.) Open-water fishing (Fig. 2b) gave similar results (slope = 0.40, y-intercept = -.32, R^2 = 0.25, p = 0.001), supplying an estimate of 0.40 for the party size coefficient (α in equation [2]).

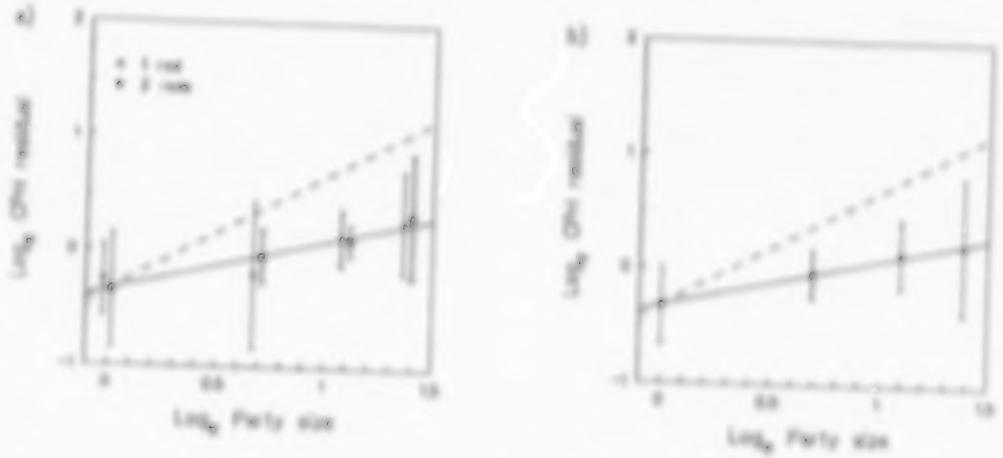

FIG. 2. The relationship between log-CPH residuals and party size for winter (a) and open-water (b) fishing. In a), results for one and two rod anglers are shown (by shifting points slightly to the left and right of corresponding party size). Vertical bars are standard deviations. Regression results are shown by the solid line in each graph. The dashed line is the relationship expected if party size coefficient (α) equals 1.

The lack of a significant rods per angler effect implies that an additional rod does not significantly increase the rate of capturing lake trout. This result was not expected. Closer examination of the data was done to see whether it was consistent across lakes and whether it depended on the abundance of lake trout. In Fig. 3, catch rates for two rod anglers (log-CPH$_2$) are plotted against catch rates for one rod anglers (log-CPH$_1$). Each point compares results for fixed party size within a given lake. The graph includes lakes which were excluded from regression analyses because data were not available for all party sizes. The dashed line is the expected relationship if two rods are twice as effective as one rod. The dotted diagonal

line is the line of equality. The relationship determined from functional regression analysis is

$$\log_e CPH_2 = 0.97 \log_e CPH_1 - 0.005 \quad [8]$$

and it corresponds almost exactly with the line of equality. This confirms previous results. It also indicates that effects are not masked by some interaction with fish abundance. This would have been indicated by a slope deviating from 1.

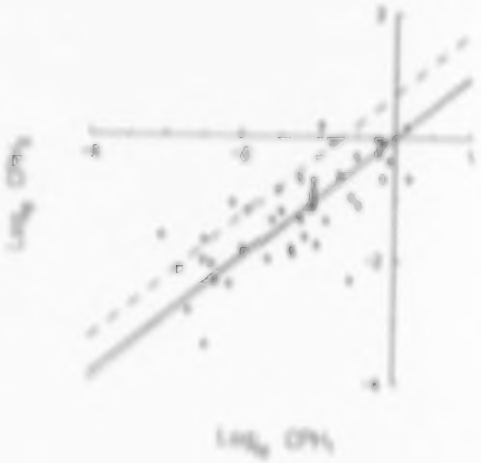

FIG. 3. The relationship between catch rates of anglers using 2 rods and 1 rod. Each point is a result for a fixed party size within a lake. Lines drawn are the regression line (solid), the line of equality (dotted) and the relationship expected when 2 rods are twice as effective as 1 rod (dashed line).

Fig. 3 illustrates that effects due to an additional rod are highly variable. It can result in capture rates that are twice as high a single rod capture rates, as indicated by several points that fall close to the dashed line in Fig. 3. These effects are discounted by cases where two rods were less effective than one rod. This suggested that an overall null effect may have been due to opposing effects in different lakes.

To examine lake differences, the rods-per-angler coefficient (γ) was calculated for each party size in each lake. From equation [5], it can be shown for a fixed party size that

$$\log_e CPH_2 = \log_e CPH_1 + \gamma \log_e 2 \qquad [7]$$

where subscripts (1,2) denote number of rods-per-angler. It follows that γ can be estimated as

$$\gamma = \frac{\log_e CPH_2 - \log_e CPH_1}{\log_e 2} \qquad [8]$$

Results for each lake are shown in Fig. 4, arranged in order from smallest effect to largest effect. The 4 bars shown for each lake are estimates γ for party sizes ranging from 1 to 4 anglers.

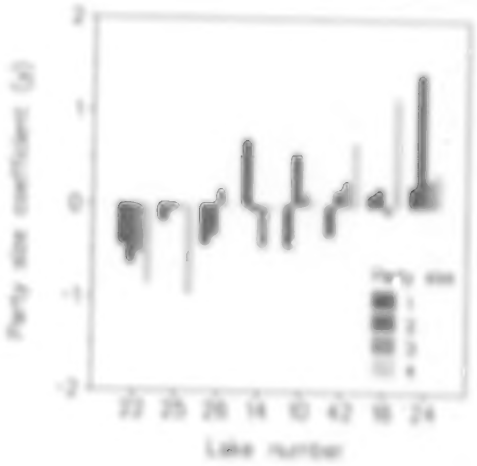

FIG. 4. Estimates of the rods-per-angler coefficient (γ) for each party size in each lake. Mean γ (averaged across party size) for each lake is: -0.87 (22 Joseph), -0.43 (25 Simcoe), -0.19 (26 Superior), 0.08 (14 Dickey), 0.10 (10 Clear), 0.29 (42 Twelve Mile), 0.51 (16 Crag), 0.80 (24 Koshkong).

The graph demonstrates that rods-per-angler effects were fairly consistent across party size in only three lakes. For Lake Joseph (#22) and Lake Simcoe (#25), the effect was negative. Anglers with two rods caught less fish per hour than anglers with only one rod. For Koshkong Lake (#24), the effect was positive

And the average effect implies y = 0.53. Thus, on this lake an additional rod was almost as effective as the first rod: anglers with two rods increased their catch-per-angler-hour by a factor of 1.8 (over anglers with only one rod). On other lakes, negative and positive effects were observed as party size varied. The average effect was approximately zero for three of these lakes (Superior #26, Dickey #14, and Esson #16) and substantially greater than zero for two of these lakes (Twelve Mile #42 and Drag #16).

DISCUSSION

The results indicate that party size and rods per angler have complex effects on angler effectiveness. Total rod-hours (i.e. trip duration x party size x rods-per-angler) is not an appropriate scale for measuring effective effort. Using equation [5] to model effects of these parameters, we have shown that both the party size coefficient (x) and rods-per-angler coefficient (y) are less than one. Party size effects are accounted for by a coefficient of approximately 0.4, implying that angler effectiveness (with respect to lake trout) decreases as party size increases. When party size doubles, CPH increases by a factor of only 1.4. Expressed in terms of catch-per-angler-hour, this implies that anglers in a party of two are 70% as efficient as solitary anglers.

Effects due to variation in number of rods per angler were small and not significant when averaged across lakes. This implies a value of 0 for y, the rods-per-angler coefficient. However, this null effect is not consistent across lakes. On some lakes, an additional rod increased catch rates; on others a negative effect was observed. In several cases, these effects varied with party size.

These results describe how catch rate varied among parties in which anglers used one or two rods. Analyses did not address the question of whether the effectiveness of a given angler is influenced by party size and/or the number of rods used. An experimental approach that manipulates conditions for known anglers would be required to investigate this. If these properties are correlated with angler fishing abilities, then effects may be attributed to differences in those abilities. This factor might explain why catch rate for

anglers using two rods was sometimes less than catch rate for single rod anglers. On Lake Superior, it has been noted that more serious anglers (as indicated by their presence in spite of bad weather conditions) typically use a single rod (K. Cullis, OMNR, Thunder Bay, Ont. P7C 5G6, pers. comm.). Presumably, these anglers recognize that the catch expected from an additional (unattended) rod is not worth the effort of setting the gear. This suggests that anglers opting for two rods are less experienced and might explain why two rods were less effective than one rod on this lake.

Species targeting is another factor to consider. Analyses reported here focused on a single species (lake trout). Effects on the catch of other species were not investigated. If anglers with two rods were targeting on different species, one does not expect an increase in catch rate for a given species. On Lake Simcoe, two-rod anglers often target on two species (C. Willox, OMNR, Sutton West, Ont. L0E 1R0, pers. comm.): one attended line seeks lake trout; the other unattended line is set for lake whitefish (*Coregonus clupeaformis*). This could explain why two rod fishing on this lake does not increase lake trout catch. It does not explain, however, why two rods were less effective than one rod.

Differences in angler abilities may also account for the observed party size effects. Larger parties are more likely to be comprised of less experienced and/or serious anglers. Novices rarely fish alone and solitary anglers probably represent a more experienced population of anglers. Thus, one expects higher catch rates for solitary anglers. This factor probably accentuates party size effects.

Another factor that may explain the party size effect is the spatial distribution of lake trout. Because lake trout tend to concentrate in certain areas, angler success rates are expected to decrease as party size increases and the magnitude of this effect is likely to depend on the abundance of lake trout. This is illustrated by considering how density affects the time spent locating a concentration of lake trout and the rate of capture once they have been located. When lake trout are abundant and very little time is spent locating concentrations, the disadvantages of party fishing are small. If lake trout are located immediately,

the catch should be roughly proportional to the amount of gear deployed. Thus, two anglers may catch twice as many fish as a single angler. When abundance is low, however, more time will be required to locate concentrations of fish. Assuming party size has little effect on the ability to locate concentrations, party fishermen will be handicapped under these conditions because the number of angler-hours spent locating fish will be higher when fishing in a group. Although catch rates per angler-hour might be independent of party size once fish have been located, overall catch rates would be less.

This theory implies that estimates of x, the party size coefficient in equation [5], should be higher when lake trout density is higher. Examination of the results (on an individual lake basis) provides some support for this hypothesis. Log-CPH (averaged across party sizes) was used as an index of fish density for each lake. Individual lake estimates of x tended to increase with this density index for both winter and open-water seasons. However, neither relationship was significant ($p = 0.05$) and it is clear that substantially larger sample sizes are needed to adequately test an hypothesis of this nature.

CONCLUSIONS

Measurement of effective fishing effort is a complex problem. Ideal solutions describing effective effort as a function of fishing duration, party size and rods-per-angler are not available because effects of the latter two variables vary across lakes. These differences may be due to fish density interaction effects. This raises the question of whether a simple catch equation (assuming constant catchability) is sufficient.

In spite of these difficulties in explaining effort factors, some practical solutions may be proposed. First, **we recommend that angler-hours be adopted as the unit for measuring effective effort**. This is recommended over rod-hours because the number of rods-per-angler has unpredictable effects on catch rates. In most cases, use of this measure would overestimate effective effort because doubling the number of rods rarely results in a doubling of catch rate. Second, **we recommend that party size and rods-per-angler always be measured and treated as qualitative aspects of fishing that influence the**

effectiveness of one angler-hour. These variables should be treated in the same way as other qualitative variables such as experience of the angler population, use of guides, and fishing methods (e.g. bait, fishing gear, fish finding gear). When these factors are constant (over time and space), effective effort can be compared on an angler-hours scale. When they vary, comparisons of the type described in this appendix are needed to calibrate their effects and obtain functional definitions of effective effort.

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Appendix C. Angling and gillnet selectivity for lake trout

INTRODUCTION

Selectivity can be considered as any factor that causes the size composition of the catch to be different from that of the population (Pope et al. 1975). Differences can arise as a consequence of differential probability of fish encountering the gear and/or differential probability of retention by the gear. In most cases, however, it is not possible to distinguish between the two factors.

A review of methods pertaining to selectivity can be found in Pope et al. (1975) and Hamley (1975). Additionally, Dahm (1987) presents a comprehensive bibliography of selectivity for inland fish species by various gears. In this appendix, we restrict ourselves to methods applicable to lake trout in Ontario lakes, namely angling and gillnetting. We review some of the techniques used to estimate selectivity, present estimates of selectivity from angling and gillnetting surveys, and discuss the effects of selectivity on estimates of mortality and growth.

DEFINITION OF SELECTIVITY

Catchability (q) is defined by Ricker (1975) as the fraction of a fish population that is caught by a defined unit of effort. It is identified in the catch equation as a proportionality constant that relates catch (C) to fishing effort (f) and the size of the fish population (N):

$$C = q f N \qquad [1]$$

Selectivity exists when catchability varies with the size of fish. It has been defined by Hamley and Regier (1973) using a size specific formulation of the catch equation,

$$C_j = q_j f N_j \qquad [2]$$

where j denotes size of fish, which implies catchability coefficients can be measured as

$$q_j = \frac{C_i}{f N_j} \qquad [3]$$

ESTIMATING CATCHABILITY COEFFICIENTS

When population sizes (N_j) of different length groups are known for a marked subpopulation (or the entire population), catchability coefficients can be measured directly (from equation [3]) as CUE (C_j/f) divided by N_j. A correction is needed if a significant portion of the population is removed during the period in which CUE is measured. Hamley (1975) suggested that each coefficient be calculated as the weighted mean of successive CUE estimates, where the weighting factor is the number of survivors at the start of each time period. That is,

$$q_j = \frac{\sum \frac{C_{jt}}{f_t}}{\sum N_{jt}} \qquad [4]$$

where subscript t refers to the time period (e.g. day, week) of the survey and N_{jt} is the number of survivors of size j at the start of period t.

When population size is not known, the Delury method (see Hamley 1972) can be used. The method requires a survey that removes a significant portion of the population and assumes natural mortality is negligible. It also assumes catchability (of each size group) is constant during the survey. Regression of successive (daily or weekly) values of CUE (C_{jt}/f_t) versus cumulative catch (C'_{jt}) is expected to yield a straight line with a slope equalling the negative value of catchability (q_j):

$$\frac{C_{jt}}{f_t} = q_j N_j - q_j C_{jt} \qquad [5]$$

Estimates of catchability are expected to vary with lake size because catchability, as defined by Ricker (1975), measures the fraction of the population captured by one unit of effort. Although fish density (N/Area), and consequently CUE, might be the same in two lakes, catchability would be less in the larger

lake because the catch represents a smaller fraction of the population. Attempts to deal with this area effect have defined catchability differently, as the probability of encountering and capturing a fish during one unit of effort (Cushing 1981). Engstrom-Heg (1986) proposed that this second definition be labelled as "specific catchability" (q') and showed that it is related to Ricker's q by the equation

$$q = \frac{q'}{Area} \qquad [6]$$

This measure of catchability (q') is more useful when comparing lakes that vary in size.

A hypothetical example that demonstrates how tag recapture data can be used to estimate catchability (q_j) and specific catchability (q_j') is given in Table 1. For illustrative purposes, we assume lake trout are tagged during fall spawning, all recaptures from winter angling are reported and winter effort has been estimated. Two lakes are used in the example to demonstrate the expected effect of lake area. Results for q_j' are summarized in Fig. 1. Although q_j values differ greatly among lakes (see Table 1), specific catchability (q_j') is similar on both lakes. Variation in q_j' with lake area may exist (Engstrom-Heg 1986), but comparisons based on q_j' will indicate whether area effects are complex and not simply the result of how catchability is defined. In Fig. 1, a logistic function has been used to describe size selectivity. Other examples of functions that have been used to describe selectivity are given in Fig. 2 (see Gulland 1969; Pope et al. 1975; Deriso et al. 1985). A suitable function depends on the pattern observed.

Table 1. Demonstration of how size specific catchability could be estimated from tag recapture data. Fork length is classified into 100 mm intervals and groups are labelled by their mid-points. Symbols are: number of tags applied (N_j), number of tags recaptured (C_j), the recapture ratio (C_j/N_j), catchability (q_j) calculated by equation [3], specific catchability (q_j') calculated by equation [6].

LAKE 1: Area = 300 ha; Effort = 2000 ang-hr						LAKE 2: Area = 800 ha; Effort = 1600 ang-hr					
Length Group (mm)	N_j	C_j	C_j / N_j	q_j	q_j'	Length Group (mm)	N_j	C_j	C_j / N_j	q_j	q_j'
50	0	0				50	0	0			
150	0	0				150	0	0			
250	0	0				250	0	0			
350	33	3	0.091	0.000045	0.014	350	44	2	0.045	0.000028	0.023
450	45	11	0.244	0.000122	0.037	450	60	3	0.050	0.000031	0.025
550	35	15	0.429	0.000214	0.064	550	83	10	0.120	0.000075	0.060
650	26	13	0.500	0.000250	0.075	650	72	10	0.139	0.000087	0.069
750	17	8	0.471	0.000235	0.071	750	50	7	0.140	0.000088	0.070
850	5	2	0.400	0.000200	0.060	850	35	5	0.143	0.000089	0.071

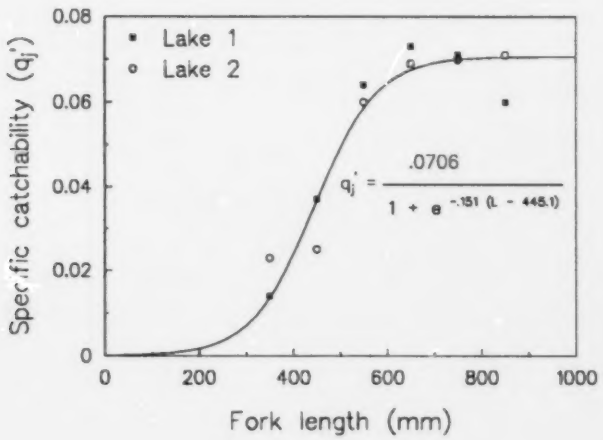
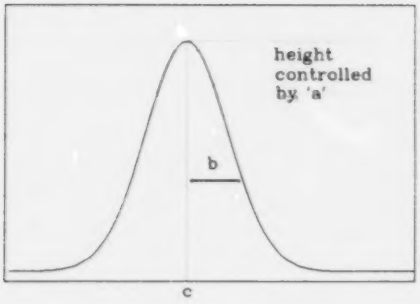


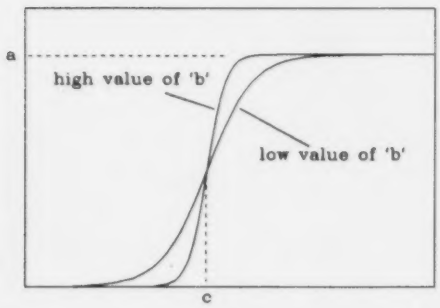
FIG. 1. Example of how size selectivity implied by data in Table 1 could be described by fitting a logistic function.



Normal function

Symmetrical and bell-shaped. Parameters a, b and c control height, width and position along the x-axis. Often used to describe gillnet selectivity.

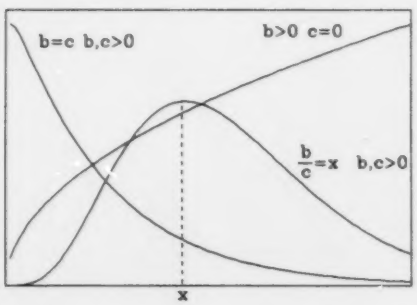
$$f(j)=a\frac{1}{b\sqrt{2\pi}}e^{-(j-c)^2/2b^2}$$



Logistic function

An S-shaped curve that may be suitable for describing trapnet selectivity or angling selectivity where large fish are targetted.

$$f(j)=\frac{a}{1+e^{(-b(j-c))}}$$



Gamma function

Flexible, and capable of describing dome-shaped, U-shaped, ascending or descending curves.

$$f(j)=aj^be^{-cj}$$

FIG. 2. Examples of functions that have been used to describe size selectivity

RESULTS FOR ONTARIO LAKES

Although effort data are needed to estimate catchability coefficients, relative selectivity can be calculated without effort data. The ratio C_j/N_j indicates whether catchability varies with length (Ryan 1989). Where m denotes the size at which this recapture ratio reaches a maximum value, relative selectivity (s_j) can be measured as

$$s_j = \frac{\left(\frac{C_j}{N_j}\right)}{\left(\frac{C_m}{N_m}\right)} \qquad [7]$$

Estimates of angling relative selectivity, based on tag recapture ratios, are shown for three lakes in Fig. 3. (Catchability coefficients were not calculated because effort data were not available.) The results show that medium sized fish are most vulnerable. They also suggest that selectivity varies depending on growth characteristics of the target population. Results for two small-sized lake trout populations are similar (Squeers and Flack), but selectivity peaks at a larger size in Lake of the Woods where lake trout growth is higher.

The gillnet results shown in Fig. 3 describe the selectivity of mixed mesh nets that have been used on Lake Ontario (Schaner 1989 and below). The graph demonstrates that catchability increases continuously with increasing length of fish. This selectivity is expected to vary depending on the type of gillnet gear and when it is employed.

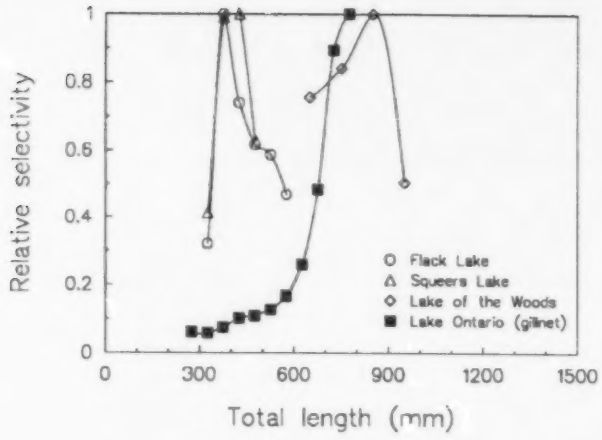


FIG. 3. Relative size selectivity of lake trout determined for angling on three lakes (Flack, Squeers and Lake of the Woods) and assessment gillnetting on Lake Ontario. Results are presented for total length because fork length data were not available in all cases.

EFFECTS OF SELECTIVITY ON ESTIMATES OF MORTALITY AND GROWTH

Bias due to size selectivity presents problems for estimating mortality and growth. Fig. 4 gives a hypothetical example that demonstrates its effects on the observed age composition and mean length-at-age from which mortality and growth are estimated. Examples below explore the bias that would result from size selectivity curves shown in Fig. 3. They were constructed by simulating size selective capture of fish. The simulation model described a population growing according to a von Bertalanffy curve, with normal distribution of lengths around each mean length-at-age. Fish were "caught" from this population according to a length selection curve. The parameters of the model (growth, mortality and selectivity) were adjusted to mimic a particular lake and fishery. To assess the effects of selectivity, we compared the input age structure and growth with the corresponding outputs (i.e. the simulated catch).

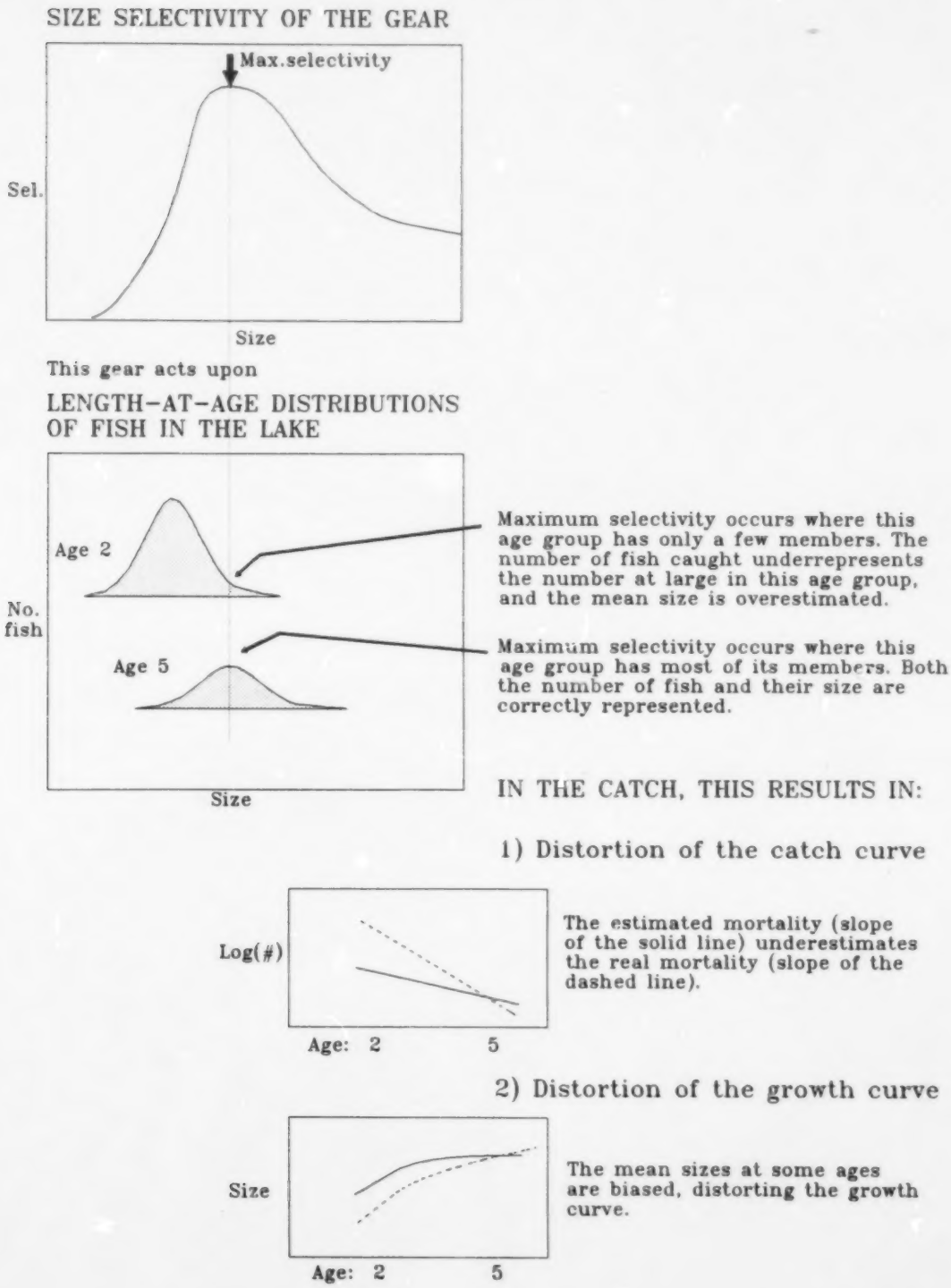

SIZE SELECTIVITY OF THE GEAR
Max.selectivity
Sel.
Size
This gear acts upon
LENGTH–AT–AGE DISTRIBUTIONS
OF FISH IN THE LAKE
Age 2
No.
fish
Age 5
Size
Maximum selectivity occurs where this age group has only a few members. The number of fish caught underrepresents the number at large in this age group, and the mean size is overestimated.
Maximum selectivity occurs where this age group has most of its members. Both the number of fish and their size are correctly represented.
IN THE CATCH, THIS RESULTS IN:
1) Distortion of the catch curve
Log(#)
Age: 2 5
The estimated mortality (slope of the solid line) underestimates the real mortality (slope of the dashed line).
2) Distortion of the growth curve
Size
Age: 2 5
The mean sizes at some ages are biased, distorting the growth curve.

FIG. 4. Demonstration of how size selectivity can result in biased estimates of mortality and growth

Example 1: Angling Selectivity in Squeers Lake

The lake trout in Squeers Lake reach an asymptotic mean length of 459 mm, and have a 75% yearly survival (Ball 1988). Angling selectivity (Fig. 3) is highest around 400 mm, corresponding roughly to a 10 yr-old fish. The selectivity curve, shown in Fig. 3, was represented in the simulation by a normal curve with mean of 400 mm and standard deviation of 90 mm.

Simulation results are shown in Fig. 5. The age composition of the catch is biased because age groups in which length is less than 400 mm are under-represented (see Fig. 5a). The slope of the catch curve, which measures total mortality, does not begin to approach the true population value until around ages 8 to 10 yr. For the ages over 10 yr, the catch curve (Fig. 5b) indicates a mortality that is higher than the true population value, with maximum bias occurring at 12 yr (27% instead of 25%). The bias decreases in the older ages.

The effect described for the younger ages is well known as "incomplete recruitment", and to compensate for it, young ages are normally discarded in catch curve analysis. It is worth noting, however, that bias exists in ages that would normally constitute the bulk of the data. The bias only becomes negligible in the older ages, where the catches would be generally small and variable and where, with lake trout in particular, problems would occur with age determination.

A growth bias due to size selectivity is demonstrated in 5b. Because the gear is most efficient at 400 mm (i.e. around age 10), larger members of young age groups and smaller members of old age groups are more likely to be captured. Consequently, the mean length of each age group is over- or under-estimated depending on whether its true value is less than or greater than 400 mm. In this example, the bias is relatively small, the largest difference between observed and actual mean lengths being only 13 mm.

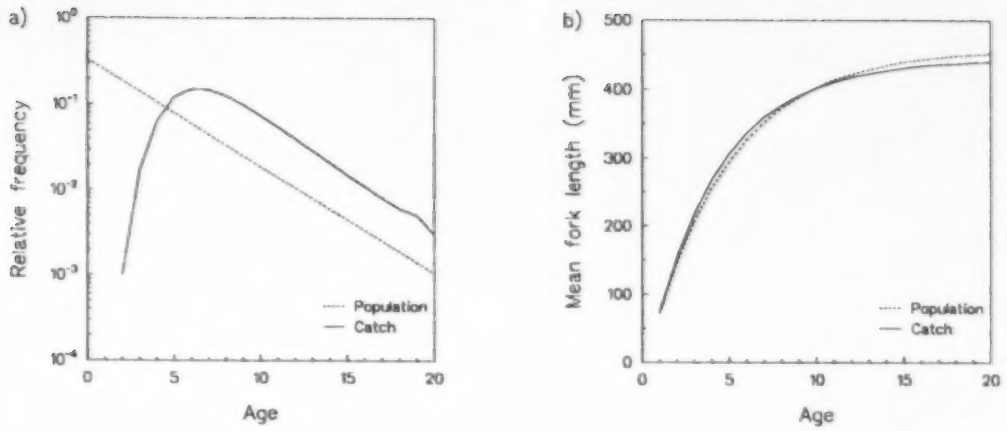


FIG. 5. Effects of angling size selectivity on estimates of age composition (a) and growth (b), based on Squeers Lake data. The POPULATION curves represent actual conditions, given model input parameters. The curves labelled CATCH show characteristics of the catch taken by anglers.

Example 2: Gillnet Selectivity in Lake Ontario

Index fishing methods used in Lake Ontario to assess lake trout employ gillnet gangs comprised of mesh sizes ranging from 5.08 cm to 15.24 cm at 1.27 cm gradation (2 in to 6 in at 1/2 in gradation). Such gear is often assumed to be free of size selection bias, because different meshes optimally fish for different sizes of fish, resulting in a flat selectivity curve. Examination of several years of data (see Schaner 1989 for details) revealed that this is not the case. Fig. 6 shows the catch frequencies by mesh size and fish size. The surface depicted in the graph consists of two "ridges" that merge into one at the largest mesh size. The diagonal ridge represents the traditional assumption, that increasingly larger mesh sizes best capture increasingly larger fish. However, the more prominent ridge that runs parallel to the mesh-size axis shows that all meshes also catch large numbers of large fish. The overall effect is that the combined meshes are more selective for large fish. Closer scrutiny of the data revealed that the diagonal ridge consists of fish caught by wedging, while the ridge of large fish that remains constant across all mesh sizes consists of fish caught by tangling.

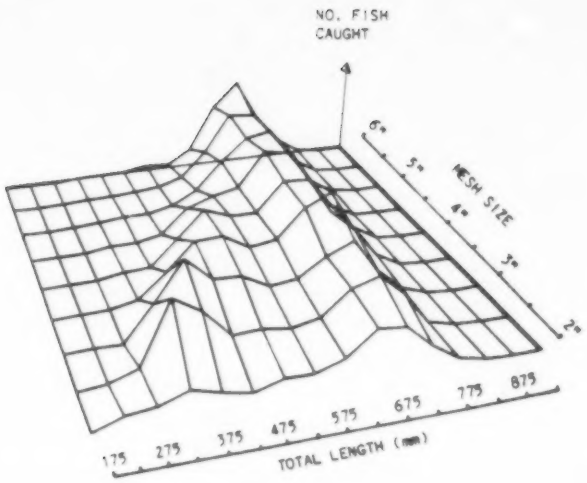


FIG. 6. Total catch of lake trout in the Lake Ontario gillnetting assessment program during 1983 and 1985 to 1987. The height of the surface indicates the number of fish of a given size in a given mesh.

The lake trout length selection curve for this gillnet gear is shown in Fig. 3. Selectivity starts rising around 550 mm and reaches a plateau around 750 mm. Estimates of selectivity for fish larger than 750 mm were uncertain. Because most of the fish in this range are tangled (not wedged), selectivity was assumed constant at the maximum level. Selectivity for fish smaller than 250 mm was assumed to be zero.

Selectivity affects estimates of both growth and mortality. Mortality estimates calculated by the slope of the catch curve (Fig. 7a) vary depending on the range of ages used in the calculation. The simulation was performed with 59% "real" yearly mortality, while the simulated catch yielded an estimate of 42% when using ages 2 through 10, or 55% when using ages 6 through 10. Mean length at age (Fig. 7b) is correctly estimated in the younger ages where selectivity is low but nearly uniform. As the length selection curve begins to rise, so does the bias, and the greatest difference is found at age 6 (size overestimated by 29 mm). With the sample sizes and variances seen in the Lake Ontario survey, this difference is significant and, depending on the application, the bias could be considered serious.

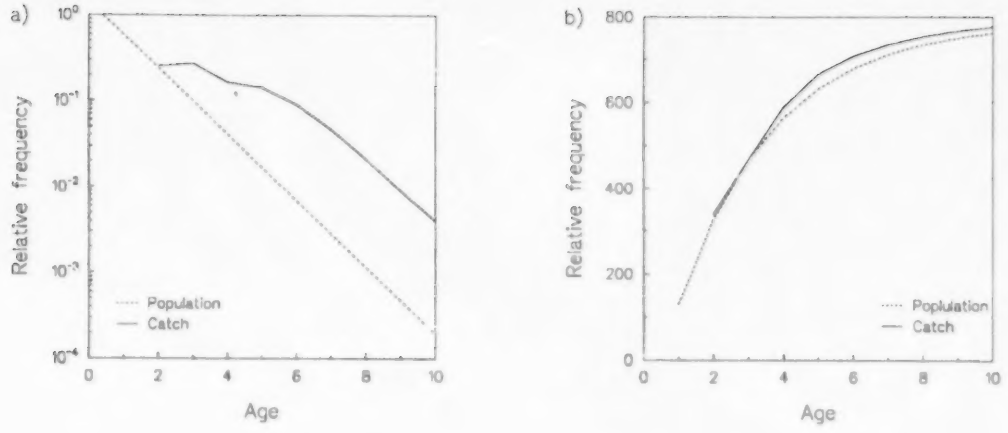


FIG. 7. Effects of gillnet size selectivity on estimates of age composition (a) and growth (b), based on Lake Ontario data. The POPULATION curves represent actual conditions, given model input parameters. The curves labelled CATCH show characteristics of the catch taken by gill nets.

Example 3: Slot Limit Imposed on an Angling Fishery

Selective release of captured fish, voluntary or mandatory, is an additional source of size bias when only harvested fish are available for sampling. In this example, we used the Squeers Lake fishery from Example 1 to simulate the effects of a protected slot. The fish population parameters and the angling selection curve were kept the same, but additionally it was stipulated that no fish between 400 and 500 mm were kept in the harvest. The lower limit of this slot corresponds to the mean size of a 10 yr-old fish, while the upper limit is reached only by larger individuals in the oldest age groups.

The effect of this slot on the catch and growth curves seen in the harvest is considerable (Fig. 8). The catch curve (Fig. 8a) indicates a yearly survival of 67% for fish between 10 and 20 yr of age, compared to the true value of 75%. The growth curve starts underestimating true growth around the age of 8 (Fig. 8b), resulting in a maximum difference of 41 mm by age 13. Both differences are on the order of 10%.

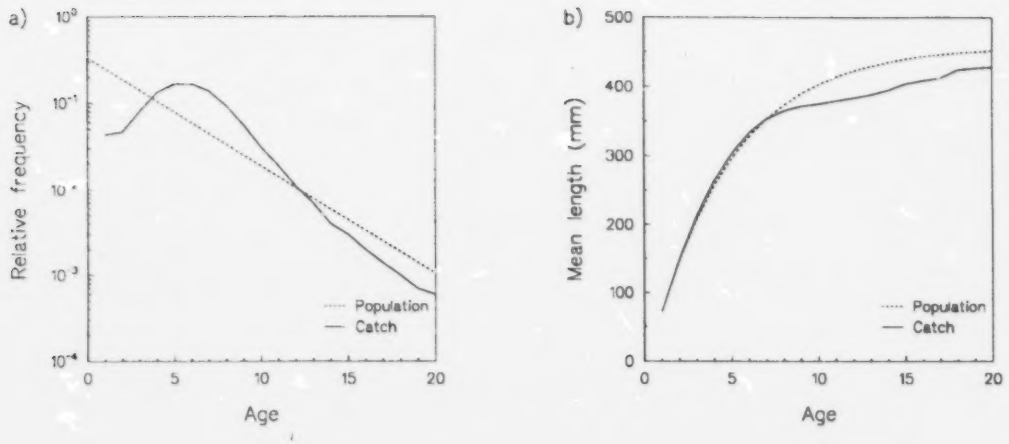


FIG. 8. The effect of a 400-500 mm protected slot on estimates of age composition (a) and growth (b), assuming released fish are not sampled. Simulation parameters were the same as in FIG. 4, with the addition of a slot.

Effects of Gear Selectivity - Conclusion

Length selection curves are difficult to generalize. Angling selectivity patterns may vary between lakes, and they may be further confounded by harvest restrictions (Fig. 3, Example 3). There is evidence that gillnet selectivity patterns are more complex than normally assumed, and overall they favour large fish (Example 2). Estimates of mortality and growth can be seriously biased by gear selectivity. Because there is a distribution of sizes at each age, and the distributions overlap, gear with abrupt selection curves can catch fish that will yield biased, but otherwise normally appearing mortality and growth patterns (Example 3).

The potential magnitude of bias, and the easily overlooked effects, warrant that selectivity be considered when working with age/size dependent statistics such as the catch or growth curves. It may be impractical to estimate selectivity in a particular lake and fishery, but it is quite easy to investigate the potential hazards

through simulation. In the case of standard gears and methods (e.g. spring gillnetting surveys proposed in this report), the size selective properties should be described and routinely compensated for.

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Appendix D. Some statistical principles.

SIMPLE RANDOM SAMPLING

The following example of data obtained by simple random sampling of an angling fishery is used to illustrate some basic statistical principles. The total number of parties that went fishing is known; a random sample of n parties have reported their effort and the numbers of fish caught and kept; and a random sample of m harvested fish have been weighed. The following notation is used to describe these data:

- N party population size (i.e. number of parties that went fishing);
- n party sample size (i.e. number of parties sampled);
- f party sampling fraction, = n / N;
- e_j effort for party j
- c_j catch for party j
- h_j harvest for party j

The following estimates (and variances of these estimates) are required:

- mean effort ($\bar{e}$) and mean harvest ($\bar{h}$) per party
- total effort (E) and total harvest (H)
- catch per angler hour (CUE)

Formulae given below illustrate how these properties are estimated when simple random sampling applies. More complex designs involving stratification and two-stage sampling usually apply in angling surveys. These designs call for different formulae which are extensions of those used in random sampling.

Mean Estimates

Mean effort and harvest per party are estimated by the formula:

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n} \qquad [1]$$

where x_j refers to effort or harvest. Variances of estimated means are calculated as

$$var(\bar{x}) = \frac{(1-f)\, s^2}{n} \qquad [2]$$

where s^2, the sample variance, is defined as

$$s^2 = \frac{\sum_{j=1}^{n} (x_j - \bar{x})^2}{n-1} \qquad [3]$$

The expression (1-f) is referred to as the finite population correction factor. This factor is applied because the variance of an estimate must be zero when all units in the population are sampled (i.e. when a census is performed).

Total Estimates

Total effort and harvest are estimated by multiplying unit means by the number of units (i.e. parties) in the population:

$$X = N \bar{x} \qquad [4]$$

The variance of a total estimate is related to the variance of the mean by the formula:

$$var(X) = N^2\, var(\bar{x}) \qquad [5]$$

Ratio Estimates

Catch-per-angler-hour is an ratio variable. It is usually estimated as mean catch divided by mean effort,

$$CUE = \frac{\bar{c}}{\bar{e}} \qquad [6]$$

which is equivalent to the ratio of the sums. Smith (1980) discussed other methods for estimating mean catch rates and the conditions under which they should be applied. The formula given above is appropriate

when variance of the catch increases in proportion to effort. Variance of this ratio estimate can be calculated as

$$var(CUE) = (1-f)\left(\frac{1}{n\bar{e}^2}\right)\left(s_c^2 + CUE^2\, s_e^2 - 2\, CUE\, \rho\, s_c\, s_e\right) \qquad [7]$$

where ρ is the correlation between c_j and e_j.

Relative and Absolute Precision of Estimates

The precision of an estimate can be expressed in relative or absolute terms. The coefficient of variation (CV) of the estimate is a measure of relative precision:

$$CV(x) = \frac{se(x)}{x} \qquad [8]$$

where x is any type of estimate (e.g. mean, total, ratio, proportion) and se(x) is the standard error of the estimate (i.e. the square root of its variance). The CV of a mean estimate is the same as the CV of a total estimate, because se(X) = N se($\bar{x}$) and X = N $\bar{x}$. CV = 0.20 implies a relative precision of 20% (i.e. the standard error is 20% of the estimate).

Absolute precision is specified by placing confidence intervals around estimates. For example, a 95% confidence interval is calculated as

$$x \pm t_{0.05}\, se(x)$$

where $t_{0.05}$ is Student's t value for n-1 degrees of freedom for the 95% level of confidence and x is any estimate. Because t values for a 95% confidence interval are almost always around 2 (unless sample size is very small), this interval is approximated by the expression

$$x \pm 2\ se(x)$$

It can also be expressed in a form that shows how absolute precision depends on relative precision. Using the coefficient of variation formula to substitute for se(x) gives

$$x(1 \pm 2\,CV)$$

Thus, if a survey obtained an estimate whose cv was 0.20, 95% confidence intervals would be approximately $\pm$ 40% of the estimate.

Sample Size Determination

When simple random sampling applies, the sample size required to meet a relative precision target can be calculated as

$$n = \frac{s^2}{\bar{x}^2\,CV^2} \qquad [9]$$

where s^2 is the sample variance and $\bar{x}$ is a mean. For 20% precision, $CV^2 = 0.04$ and equation [9] can be expressed as

$$n = 25\,\frac{s^2}{\bar{x}^2} \qquad [10]$$

This determination of sample size applies for sampling infinite populations. A correction for sampling a finite population of size N units is obtained by the formula (see Krebs 1989)

$$n^* = \frac{n}{\left(1 + \frac{n}{N}\right)} \qquad [11]$$

where n^* is the adjusted sample size.

Results from previous surveys should be consulted when planning a survey to determine what values are expected for the mean and variance. The best source of data is from a previous survey of the same lake. Historical values of the sample variance (s^2) and mean ($\bar{x}$) can be substituted into equation [10] to calculate the required sample size.

When historical data from many surveys are available, variance-mean relationships can be described so that sample size requirements can be determined from an expected mean. An approach that often works reasonably well is to use a power function in describing the variance-mean relationship:

$$s^2 = a\,\bar{x}^b \qquad [12]$$

where a and b are parameters to be determined (Taylor 1961; Elliot 1977; Downing 1979; Green 1979). When this model applies, the sample size formula for 20% relative precision becomes

$$n = 25\,\frac{a}{\bar{x}^{2-b}} \qquad [13]$$

VALIDITY OF THE NORMAL APPROXIMATION

The sampling theory described above assumes that sample estimates are normally distributed. When sample size is large this assumption is reasonable. The central limit theorem states that for any population that has a finite standard deviation the sample mean tends to normality as sample size increases. How large the sample must be so that the normal approximation applies depends on the extent to which distributions of variables sampled deviate from normality.

Distributions of many fisheries variables (e.g. activity counts, catch per party, fish weight) are characterized by marked positive skewness, with very few large values and many small values. If sample size is small, the standard deviation of the mean (i.e. standard error) is likely to be underestimated when calculated as $s/\sqrt{n}$. Consequently, the precision implied may be greater than what actually exists. Caution is advised

when interpreting results based on small sample sizes. Cochran (1977, p. 42) suggested the following rule when sampling populations in which the principal deviation from normality consists of marked positive skewness:

$$n > 25\ G_1^2$$

where G_1 is Fisher's measure of skewness. The rule is designed so that a 95% confidence statement will be wrong not more than 6% of the time.

For ratio estimates (e.g. CUE), Cochran (1977, p. 156) suggested that the normal approximation holds reasonably well if the sample size is at least 30 and is large enough that the coefficients of variation of numerator (e.g. mean catch) and denominator (e.g. mean effort) are both less than 0.1. When these conditions do not apply, the formula for variance of a ratio estimate [7] tends to give values that are too low.

TWO-STAGE SAMPLING DESIGNS

Simple random sampling rarely applies in angling surveys. In most cases, the units sampled are selected in two stages by, first, randomly selecting sample days and, then, randomly selecting units within each day (e.g. parties). Because sampled units do not represent a random sample of the population, different formulae are used to calculate means and totals and variances of these estimates. The basic principle is calculation in two stages: means are first calculated within each sample day, then a mean of means is calculated across days. Similarly, variance is calculated first within days and then among days. The precision of an estimate therefore depends on two sample sizes: number of days and number of units sampled per day. Guidelines for two-stage designs must therefore specify what combinations of sample sizes (days and within-day units) are needed to estimate variables at desired levels of precision.

STRATIFICATION

Stratification divides a target population into several sub-populations whose characteristics are determined independently and then combined to obtain survey estimates. The technique is usually employed to improve the precision of survey estimates. It is successful when the sub-populations are more homogeneous than the population as a whole. In creel surveys, temporal strata based on day types (weekday or weekend/holiday) and blocks of days (date ranges) are usually defined for this purpose. Strata may also be defined for practical reasons. For example, spatial stratification is often used to divide the survey area into manageable sized areas for sampling purposes.

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Appendix E. Glossary of symbols

Symbol	Variable	Units
a	weight-length parameter	
A	total annual mortality	prop. or % yr^{-1}
Ā	mean activity	# parties
A400	expected age at 400 mm FL	mm
Area	surface area of lake	ha
b	weight-length parameter	
B_l	seasonal catchability weighting factor	
C	catch	# fish
C_s	targeted catch	# fish
C'	cumulative catch	# fish
CPH	catch-per-party-hour	# hr^{-1}
CUE	catch-per-unit-effort	# ang-hr^{-1}
CUE_s	targeted CUE	# ang-hr^{-1}
$CUE_{s,t}$	targeted CUE for age t fish	# ang-hr^{-1}
CV	coefficient of variation	
E	angler-effort	ang-hr
E_s	targeted angler-effort	ang-hr
f	effective effort	ang-hr
f	sampling fraction (Appendix D)	
F	instantaneous rate of fishing mortality	yr^{-1}
G_1	Fisher's measure of skewness	
h	fishing duration	hr
H	harvest	# fish
H_s	targeted harvest	# fish

HUEW	harvest-weight-per-unit-effort	kg ang-hr^{-1}
$HUEW_s$	targeted harvest-weight-per-unit-effort	kg ang-hr^{-1}
K	growth rate parameter	
K_m	midday bias factor	
L	fork length	mm
L_t	fork length at age t	mm
L_∞	asymptotic length parameter	mm
MAC	mean midday activity count	# parties
ML400	mean length of fish > 400 mm FL	mm
m	sample size (second stage)	
N	population size	# fish
N	stratum size	# days
n	sample size (first stage)	
p	party size	# anglers
P_d	post-release mortality	prop. yr^{-1}
P_e	proportion of effort directed at lake trout	
P_h	proportion of the catch harvested	
P_t	proportion of fish of age t	
q	catchability	
q'	specific catchability (= q/Area)	
r	rods-per-angler	# rods
s^2	sample variance	
se(x)	standard error of estimate x	
S	annual survival	prop. yr^{-1}
S_j	selectivity	
t_0	theoretical age at which fish length is zero	yr

T	fishing day length	hr
var(λ)	variance of estimate x	
W	harvest weight	kg
w	weight of a fish	kg
Z	instantaneous rate of total mortality	yr^{-1}